Bradshaw & Hobbs

The Effect of Power Factor On the Accuracy of Integrating Wattmeters

Electrical Engineering

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THE EFFECT OF POWER FACTOR
ON
THE ACCURACY OF INTEGRATING WATTMETERS

BY

PERCY BELMONT BRADSHAW
HORACE GAYLORD HOBBS

THESIS
FOR THE
DEGREE OF BACHELOR OF SCIENCE
IN
ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING
UNIVERSITY OF ILLINOIS

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PERCY BELMONT BRADSHAW and HORACE GAYLORD HOBBS

ENTITLED EFFECT OF POWER FACTOR ON THE ACCURACY OF

INTEGRATING WATTMETERS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

J M Bryant
Instructor in Charge.

APPROVED: Morgan Brooks.

HEAD OF DEPARTMENT OF Electrical Engineering

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INTRODUCTORY.

During the 1908 inspection trip of the senior Electrical Engineers, the question of the reliability and operation of alternating current wattmeters on loads of low, or varying power factor arose. Since no very complete data concerning this phase of wattmeter operation was at hand, it was decided to make this the subject for thesis investigation.

The object of this thesis then, is to investigate the effect of power factor on the accuracy of the integrating wattmeter.

Three types of single-phase wattmeters were investigated; the Thomson or commutator type, represented by the Type M meter of the General Electric Company, the Sangamo, or so called mercury motor type, as represented by the Type E meter, made by the Sangamo Electric Company, and the induction meter type, as represented by the Type K meter of the Fort Wayne Electric Works.

GENERAL METHOD OF INVESTIGATION:

The general method of working was as follows: Each meter was first carefully tested and adjusted to run accurately at half load for the constant given by the maker. The meter was then carefully tested and calibrated for loads varying from approximately one quarter full load current, or slightly less, up to one and one quarter load current at 100 per cent power factor. The pressure on the meter was kept as constant as possible at 110 volts and a frequency of 60 cycles.

The meter was then tested under the same constant conditions as before, except that the power factor of the circuit was varied from 10 per cent to 100 per cent; a full set of load readings being taken at each power factor.

From this data the true constant of the meter was carefully calculated for each load, and the difference between it and the constant as given by the maker noted.

In order to obtain the true constant of any given meter, the instrument was run at the given load and power factor and the time for a certain number of revolutions of the dampening disc obtained by means of a stop watch. The seconds, the corresponding number of revolutions of the disc, and the watts load as measured by an indicating wattmeter, were then substituted in the formulae for finding the constant as given by the maker of the meter under test. Two sets of observations were taken at each power factor and load,

the mean of the two being used as the data for platting the curves.

Curves showing the percent of error in the constant as given by the maker, compared with the true constant of observation at 100 per cent power factor, were then platted, using per cent of error as ordinates and per cent of load current as abscissae. The calibration curve of the meter at 100 per cent power factor was used to eliminate the errors inherent to the meter itself, not due to power factor. This gave a curve showing the error due only to the effect of power factor upon the operation of the meter. Power factors of 10-20-30-40-50-60-70-80-90 and 100 per cent were investigated and the results shown graphically as above.

A curve between true constants of observation as ordinates and the corresponding per cents of load current as abscissae, was also platted for each power factor. To obtain the various power factors use was made of a double alternator. This consists of two exactly similar machines mounted on the same bed plate. The armatures of the two machines are rigidly connected together by an insulated union at one end of either shaft. The field of one machine is mounted so that it maybe rotated thru a large angle about the armature axis. The field of the other machine is fixed in position as usual. The armature of the non-adjustable machine is connected thru the current coils of the wattmeter in use, to an adjustable non-inductive resistance. The pressure coil of the wattmeter is then connected to the

armature of the adjustable generator thru a transformer. Current to energize the fields of the two machines was taken from storage battery. The two machines were driven by a D. C. motor supplied with current from storage cells. The speed and excitation of the machines were then adjusted so as to obtain a pressure of 110 volts at 60 cycles. This condition was kept constant thruout the test by the necessary adjustments of the rheostats. By rotating the adjustable field of the pressure generator thru the proper angle, and thus varying the relative angular position of the fields of the two machines, any desired phase angle between the currents in the pressure and current coils, respectively, of the wattmeter may be obtained.

Knowledge of the phase angle of the currents in the shunt and series coils of the meter is not so much desired as the power factor of the circuit. This is obtained by taking both volt, ampere and watt readings and substituting in the formula,

$$P.F = \frac{Watts}{E \times I}$$

It was found that in order to keep the power factor constant, adjustment of the alternator must be made at every load. This is because the reactance drops in the armatures of the two machines are different, and for the reason that the reactance drop of the armature supplying the current varies as the load is changed, and thus changes the phase and wave form of the generated pressure.

TABLE OF SYMBOLS.

E' = E.M.F. impressed on pressure element of meter.

I' = Current through primary of transformer.

R' = Resistance of primary of transformer.

E'_L = Useful E.M.F. inpressure element.

I'' = Current through pressure element of meter.

E''_L = Total E.M.F. induced in the secondary of transformer.

E'' = E.M.F. at terminals of secondary of transformer.

R'' = Resistance of pressure circuit of meter.

I = Load current, or current through series coils of meter.

ϕ = Angle of phase difference between E and I.

θ = Angle between E'_L and I' .

β = Angle between E'_L and E' .

α = Hysteretic angle.

Φ = Magnetic flux due to current element.

T = Torque.

K = Constant.

n = Number of turns in current coil.

n'' = Number of turns in pressure coil.

Φ'' = Magnetic flux due to pressure element.

I_d = Eddy current induced in the disc.

E_d = E.M.F. induced in the disc.

X = Position Φ'' would occupy if the pressure circuit were purely inductive.

ρ = Angle between Φ'' and X .

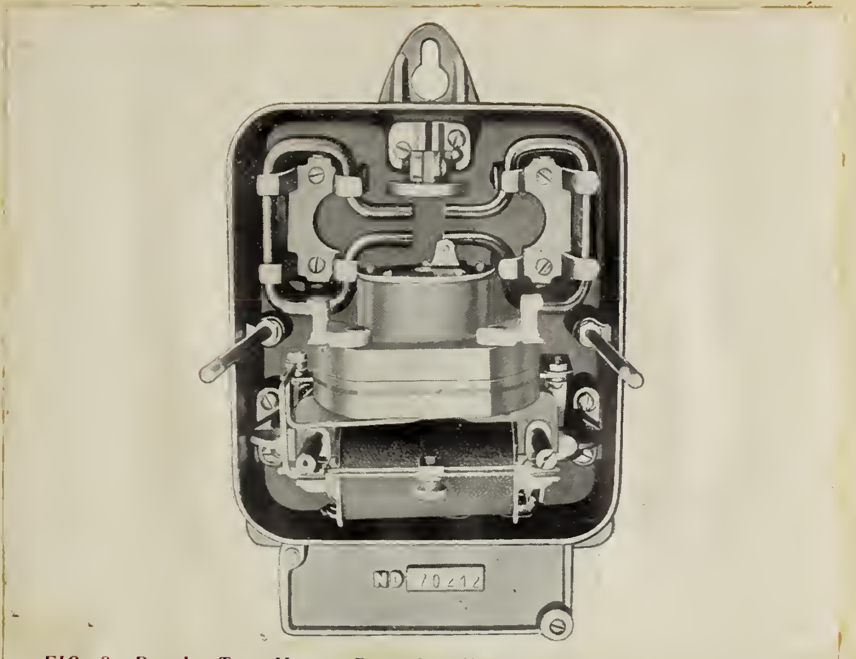


FIG. 3– Regular Type Meter, Recording Train and Damping Disc Removed.

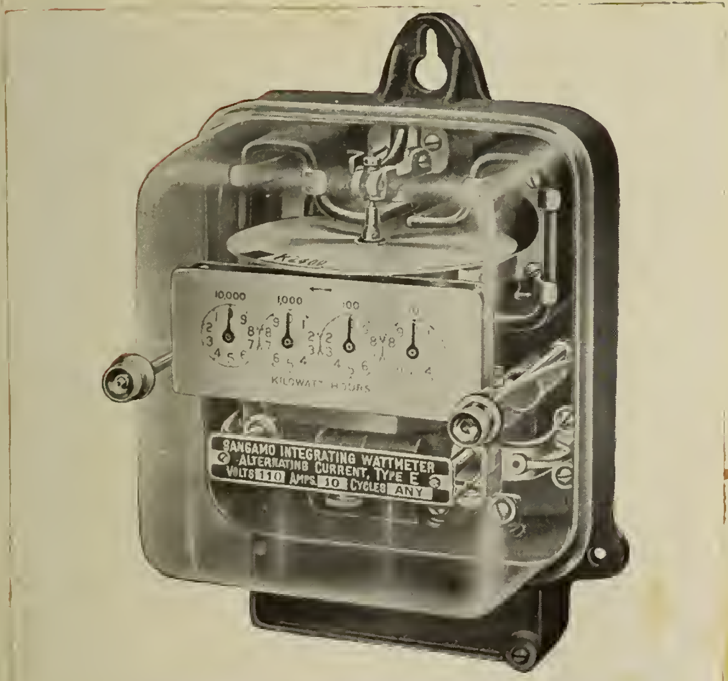

10,000
1,000
100
10
KILOWATT HOURS
SANGAMO INTEGRATING WATTMETER
ALTERNATING CURRENT, TYPE E
VOLTS 110 AMPS 10 CYCLES ANY

FIG. 6. TYPE "E"—ALTERNATING METER, GLASS CASE.

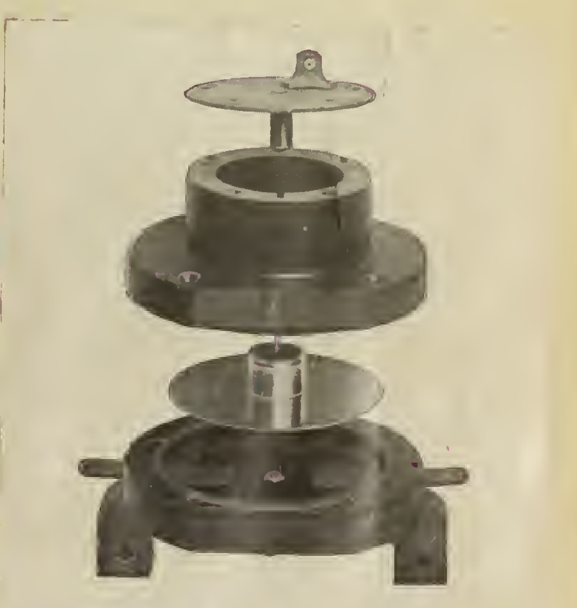


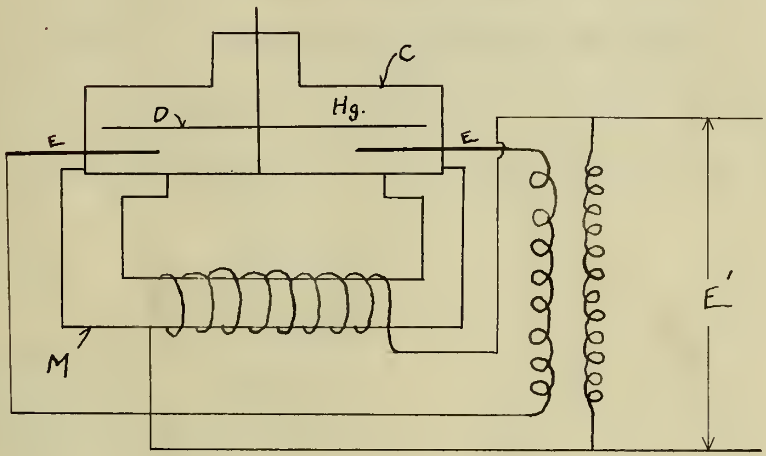
FIG. 2. MOTOR ELEMENT, EXPLODED VIEW.

SANGAMO INTEGRATING WATTMETER.

ALTERNATING CURRENT.--TYPE E.

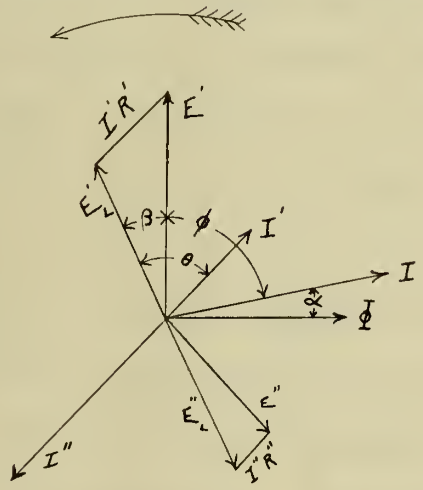
VOLTS 110-AMPERES 10-CYCLES 60.

This meter is based upon the principle of the Faraday disc, with such additions and modifications as required for operation as a wattmeter.



The motor element consists of a small metal disc "armature" D immersed with a central float in mercury, Hg, all contained within a Chamber C, formed of insulating material. The mercury chamber is in two parts, the upper having imbedded in it two metal contact ears, E,E, for carrying current into and out from the mercury and disc armature. The poles of a laminated iron magnet, M, rest against a thin pressed metal piece which forms the bottom of the lower half of the mercury chamber. A small transformer carried in the back of the meter case has its primary directly across the external circuit as shown, and a low potential secondary connected directly to the ears of the disc chamber. The laminated iron magnet M, has wound upon it a series coil which carries

the load current and hence has a field varying with that current. The armature disc of this meter constitutes the pressure element, and receives constantly from the transformer a large alternating current "I", proportional in amount to the line of pressure E but lagging $[180^\circ + (\theta^\circ - \beta^\circ)]$ behind the latter. θ is the angle of lag of the primary current of the transformer, β is the angle due to the I R drop in the same. Since the pressure is kept at a constant value, the current thru the armature I will be constant in value and hence the angles θ and β will also be constant.



Now the load current I which lags ϕ behind E' produces a flux Φ thru the magnet M, which varies with the value of the said current. Due to the iron core Φ lags behind I by the hysteretic angle α, whose value depends upon the magnetic density and the quality of iron in the core.

Since the current I'' passing thru the armature is acted upon by the flux Φ, it is evident that the torque due to the reaction between the two will be:

$$
\begin{aligned}
T &= KI''\Phi \cos\left\{\theta + [180-(\alpha+\phi+\beta)]\right\} \\
&= KI''\Phi \cos[180-(\alpha+\phi+\beta-\theta)] \\
&= -KI''\Phi \cos(\alpha+\phi+\beta-\theta) \\
&= -KI''\Phi \cos[\phi+(\beta+\alpha-\theta)]
\end{aligned}
$$

where ϕ is the angle of lag of the main circuit. Now since the pressure across the shunt element is kept constant the angles $(\beta-\theta)$ will all be constant so that the torque formula can be written

$$T = KI''\Phi \cos(\phi + K' + \alpha)$$

Now the value of I and α would be constant for a given load current, so that at constant load and varying power factor the torque would depend upon the cosine of the angle ϕ plus a constant angle $(K'+\alpha)$. While the torque tends to vary as the power factor, or the angle ϕ, the uncertainty of the effect of the constant angle $(K'+\alpha)$ upon the whole torque angle would make any indication of the meter uncertain and irregular for different power factors, even at the same load, as explained in discussion. At constant power factor and varying loads the value of the angle α as well as I would change, hence the torque would again be irregular. These effects may also be seen from an inspection of the curves themselves.

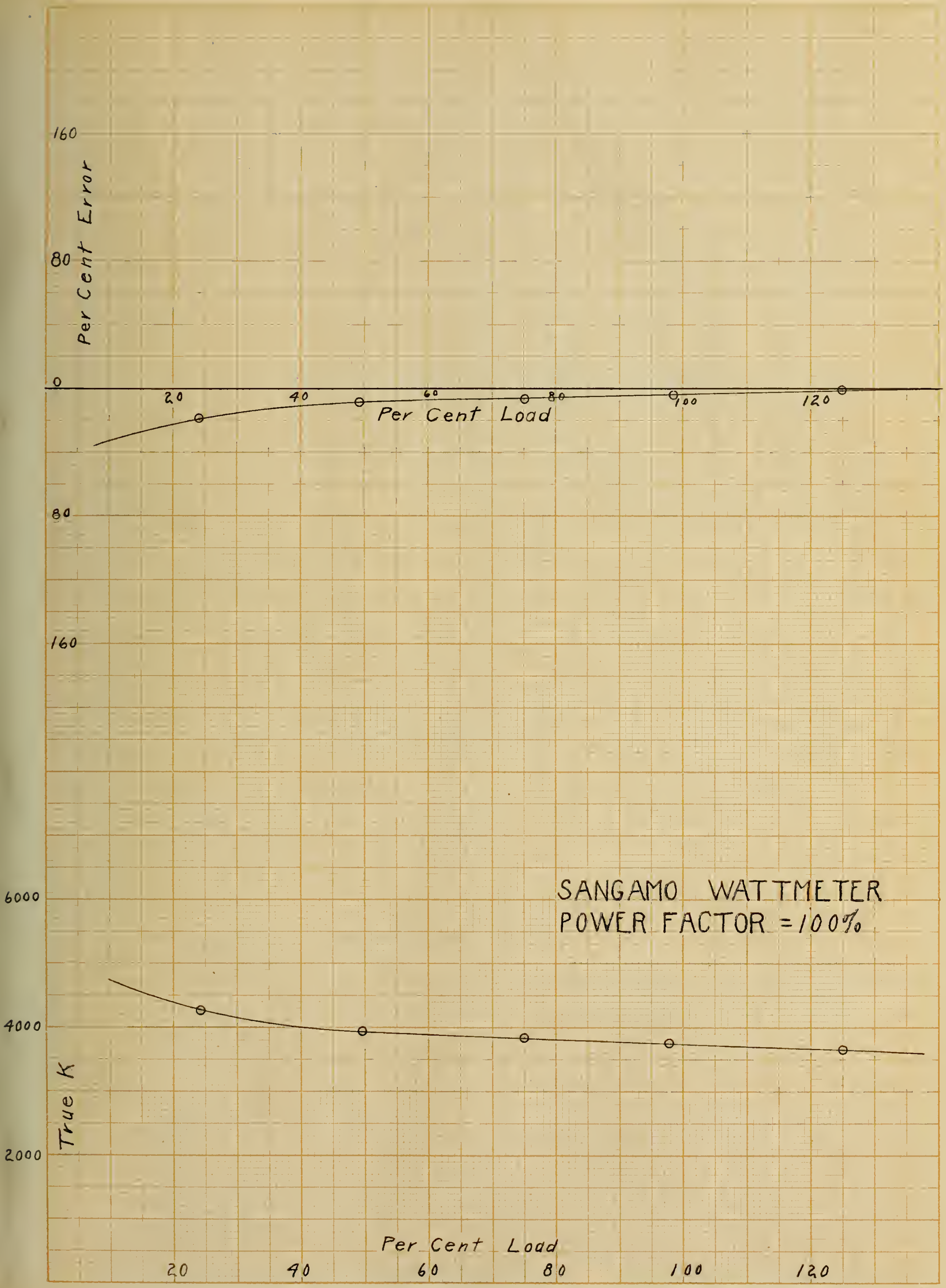
DISCUSSION OF CURVES FROM THE SANGAMO METER.

It will be noticed for the curve at 90 per cent power factor, that while the error is nearly uniform up to 80 per cent load, at what point it suddenly increases by forty per cent, indicating greater accuracy on the large loads than on the smaller. The per cent of error at 80 per cent power factor is very nearly constant, indicating that the effect of power factor is here practically constant for all loads. At 70 per cent power factor the error curve is very nearly parallel to the calibration curve of the meter, indicating an error increasing in a very similar manner to the error of calibration. The same thing is true at 60 per cent power factor, with the difference that the errors on low loads increase more rapidly than at 70 per cent power factor.

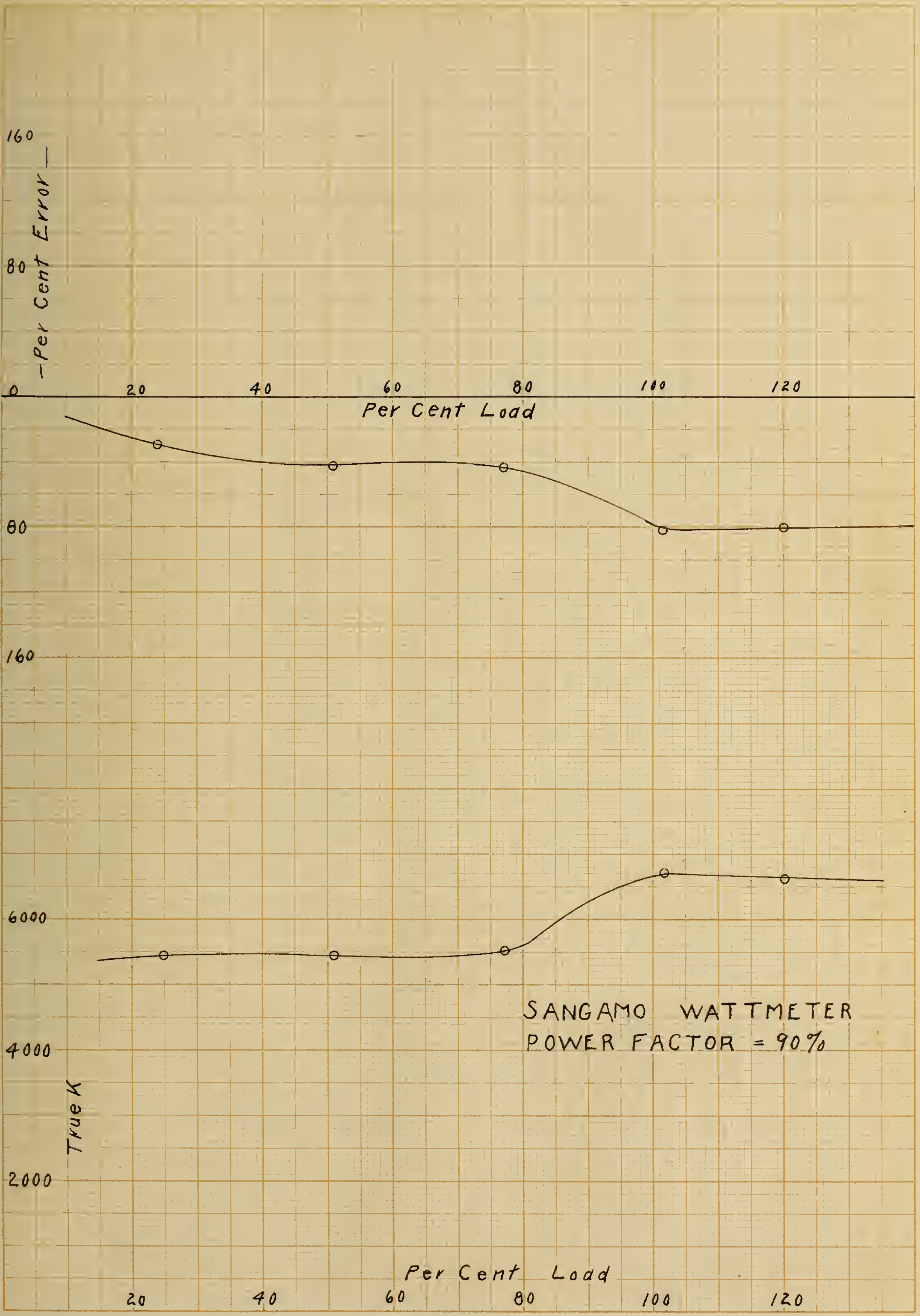
At 50 per cent power factor the curve of errors takes an entirely different turn, the error being least on overloads and on very small loads, and increasing rapidly for the intermediate points. At a power factor of 40 per cent conditions are very similar to the foregoing, the error at the higher loads being smaller and at the lower loads greater than similar points on the 50 per cent curve. At 30 per cent power factor the meter was creeping backwards, but too slowly to get satisfactory data for a curve. At 20 per cent power factor the curve is very irregular, especially for intermediate loads, the error decreasing for both the higher and the lower values of load. This is also more or less true for 10 per cent power factor, the error being more nearly uniform however.

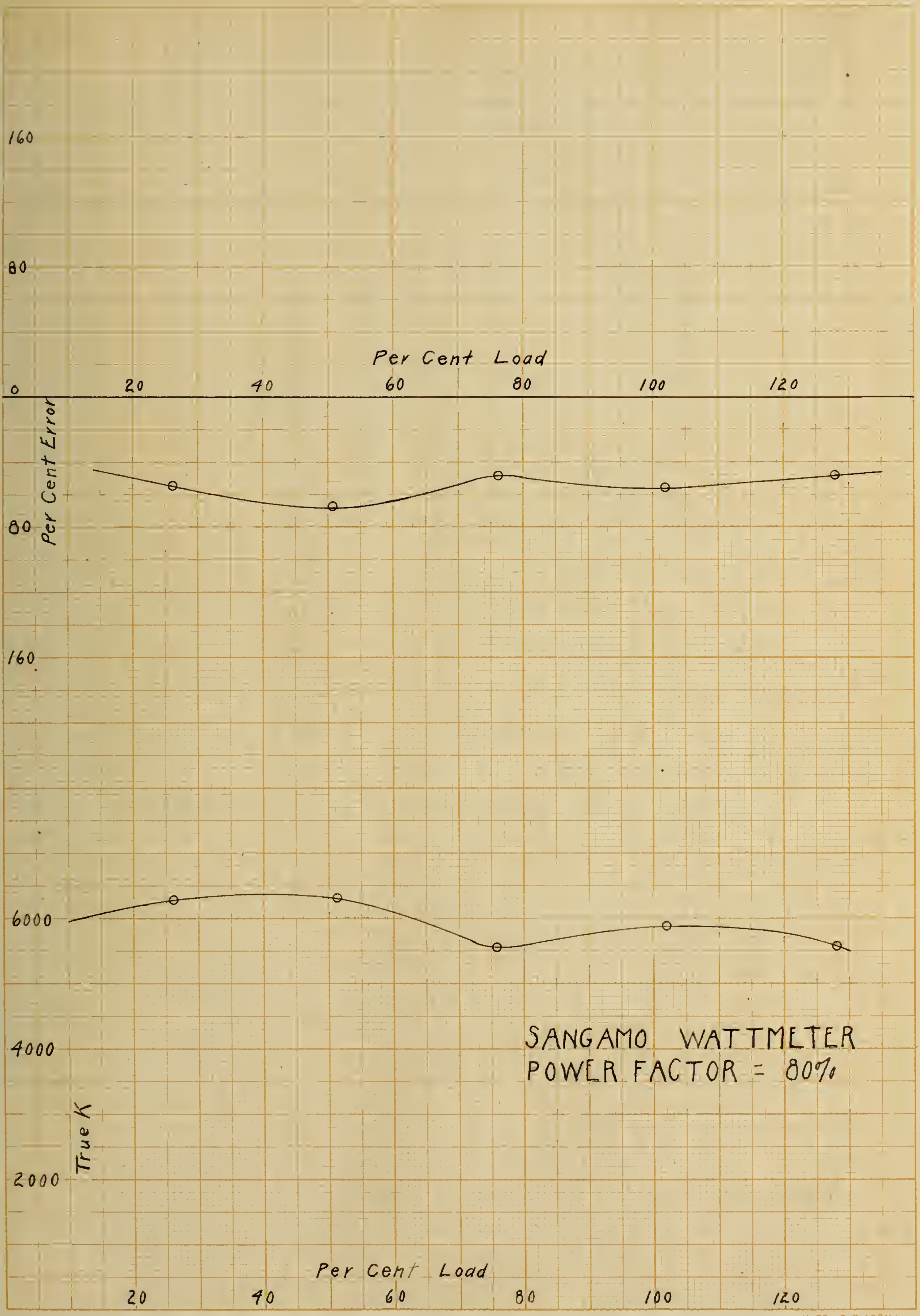
It will be noticed that the average error for power factors increases as the power factor decreases, and that for the lower factors the error is least for very small or very large loads, the intermediate points being the most unsatisfactory notwithstanding the fact that the meter was calibrated and adjusted at 50 per cent. load.

While the error *seems* to have decreased at power factors of 10 and 20 per cent, this is not truly the case, for the errors indicated are those of rotation only, the fact that the meter here runs backward being entirely neglected. If the acutal *indications* of the meter were considered, the error would be greatest here, the consequent subtraction of the readings making this meter entirely undesirable where such low power factors are to be encountered.

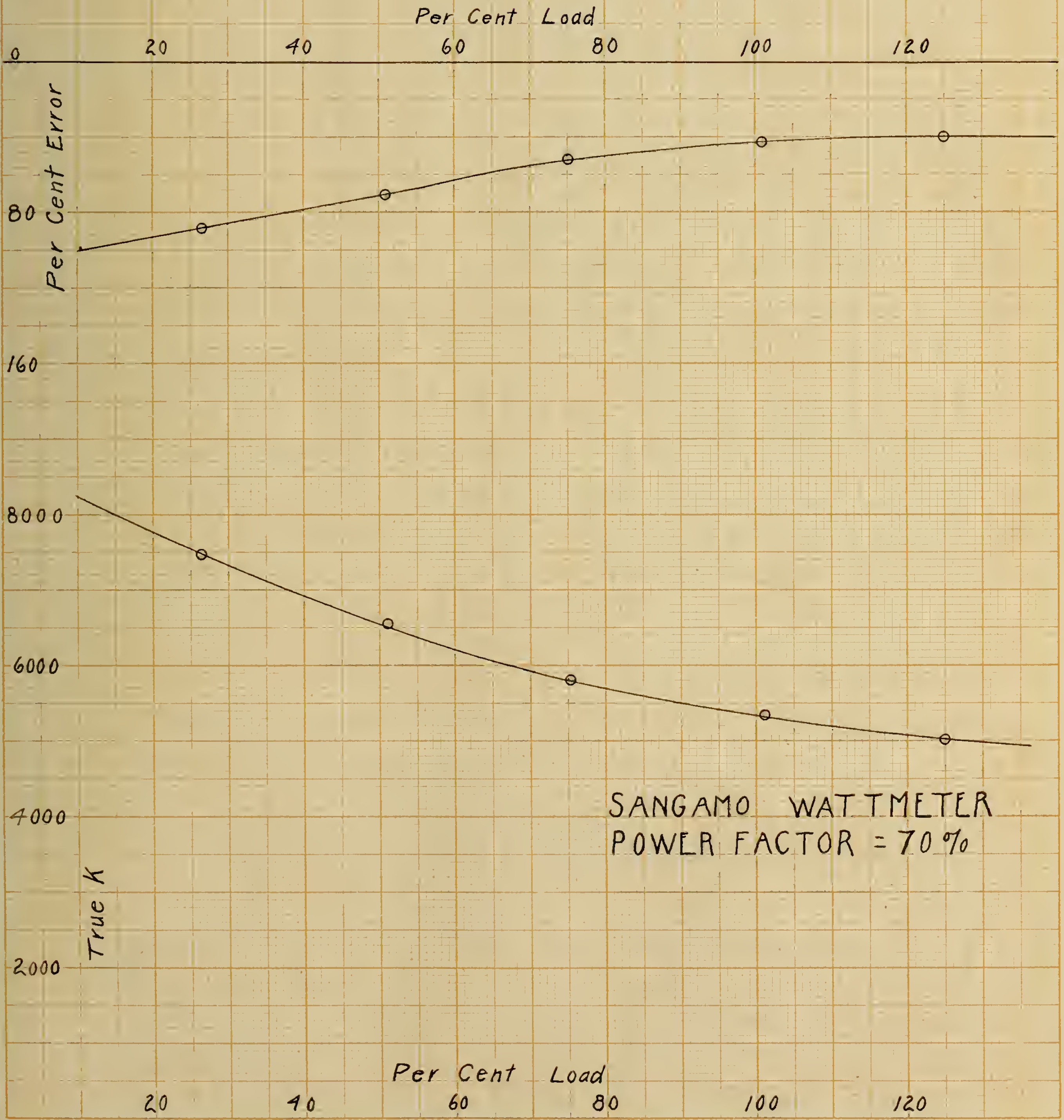

SANGAMO WATTMETER
POWER FACTOR = 100%
Per Cent Error
160
80
0
20
40
60
80
100
120
Per Cent Load
80
160
True K
6000
4000
2000
Per Cent Load
20
40
60
80
100
120

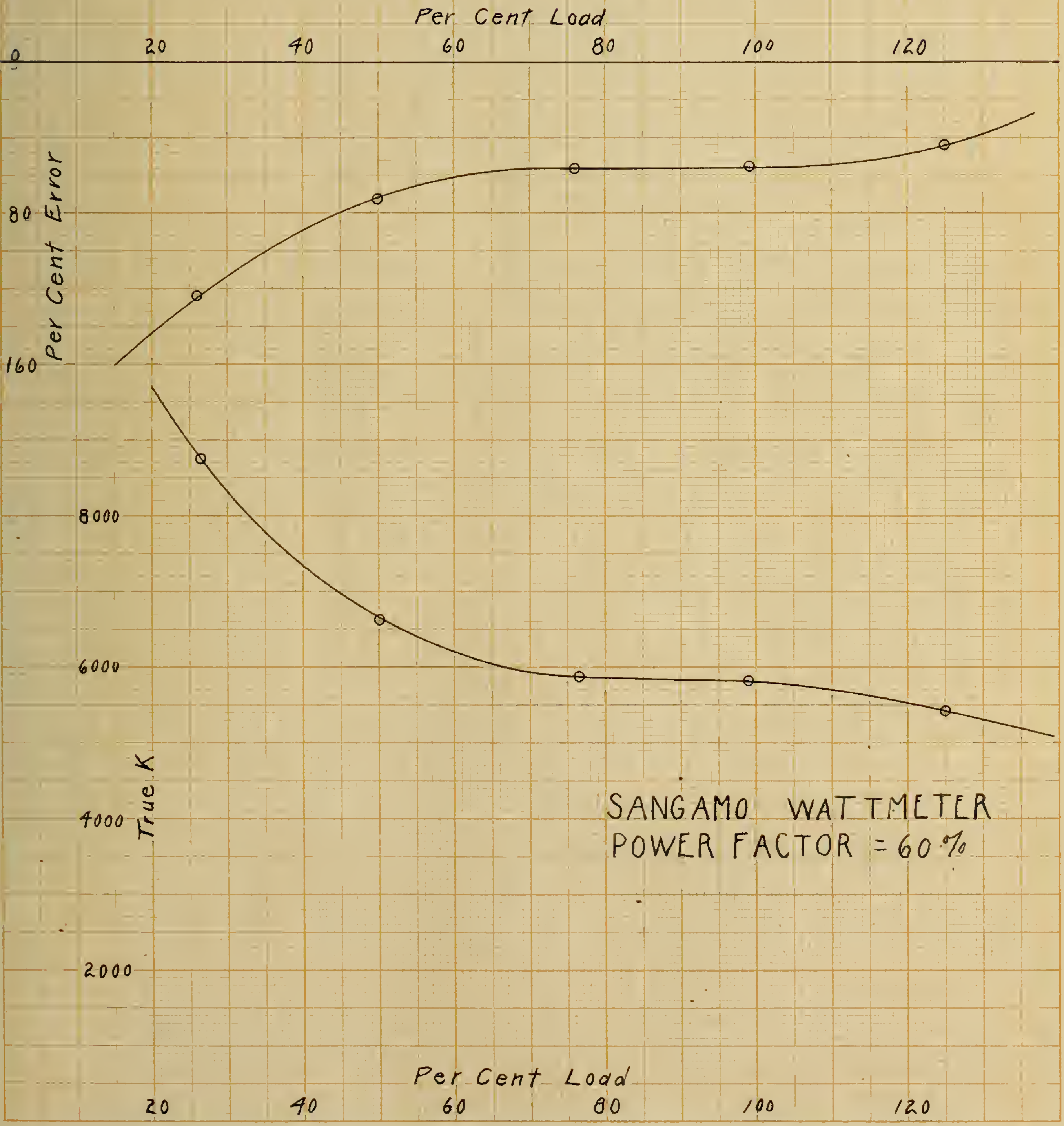
U OF I S S FORM

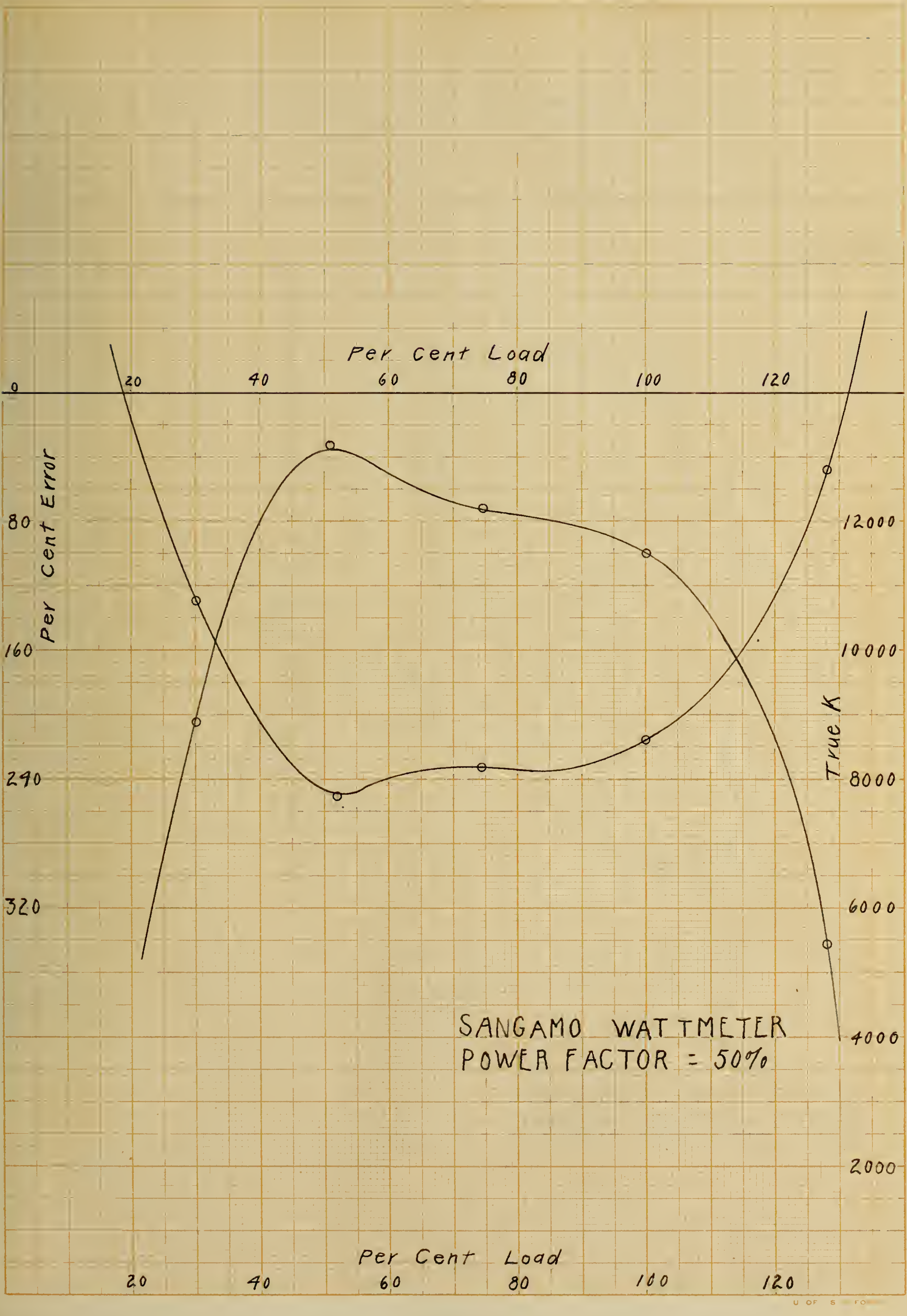

160
80
0
-Per Cent Error
20
40
60
80
100
120
Per Cent Load
80
160
6000
4000
2000
True K
SANGAMO WATTMETER
POWER FACTOR = 90%
Per Cent Load
20
40
60
80
100
120

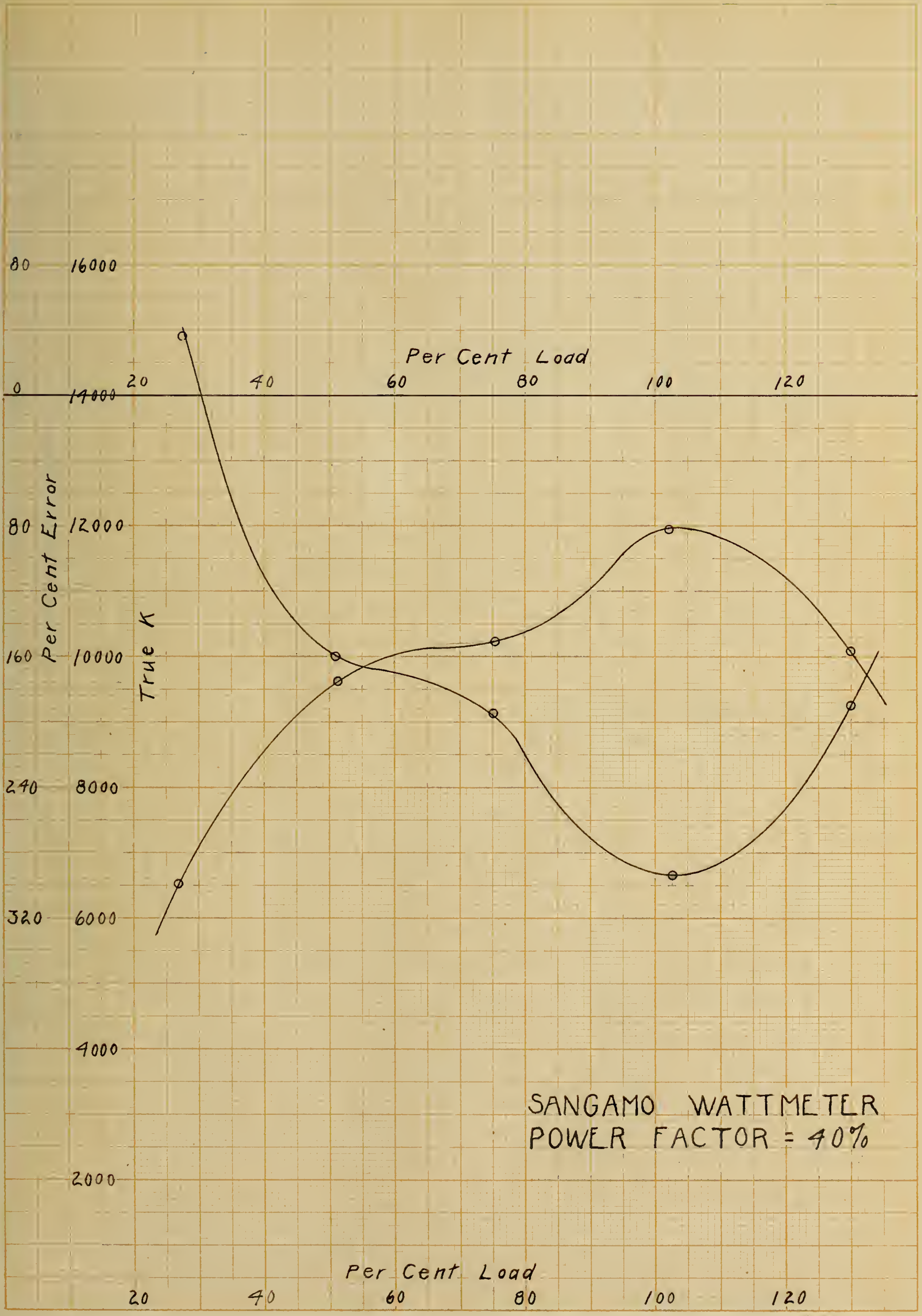

160
80
Per Cent Load
0
20
40
60
80
100
120
Per Cent Error
80
160
6000
4000
2000
True K
SANGAMO WATTMETER
POWER FACTOR = 80%
Per Cent Load
20
40
60
80
100
120

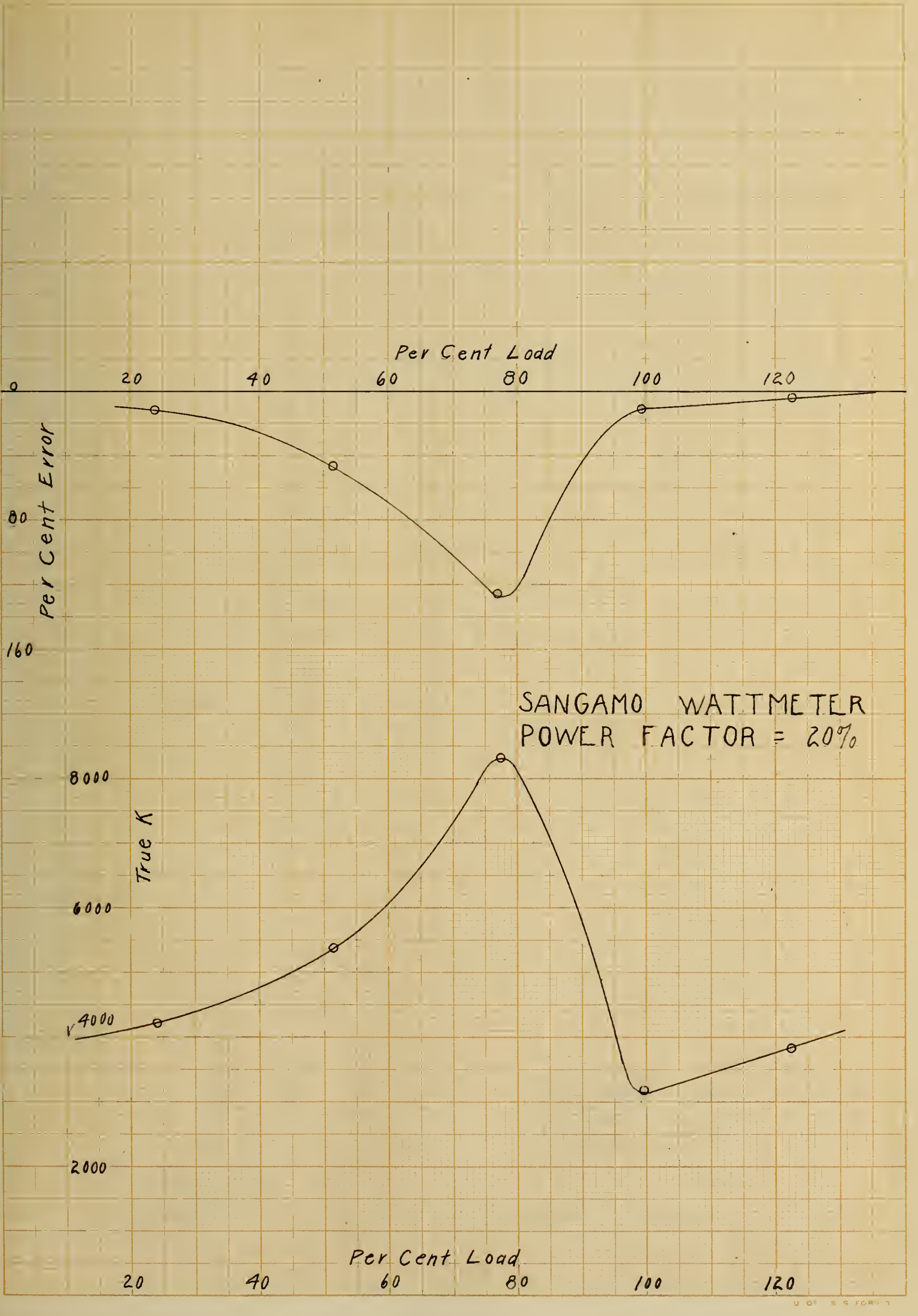
U OF I S S FORM

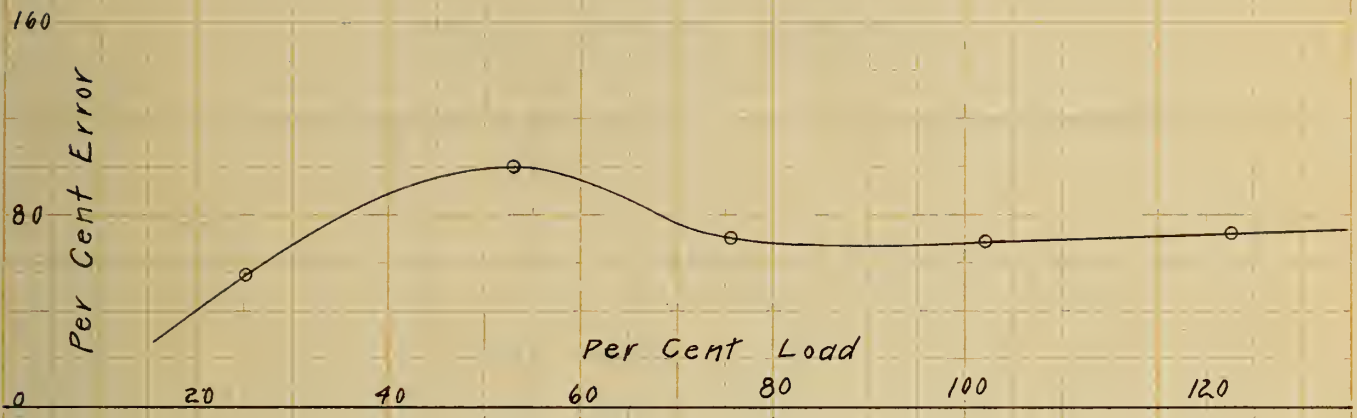

Per Cent Load
0
20
40
60
80
100
120
Per Cent Error
80
160
8000
6000
4000
2000
True K
Per Cent Load
20
40
60
80
100
120
SANGAMO WATTMETER
POWER FACTOR = 70 %

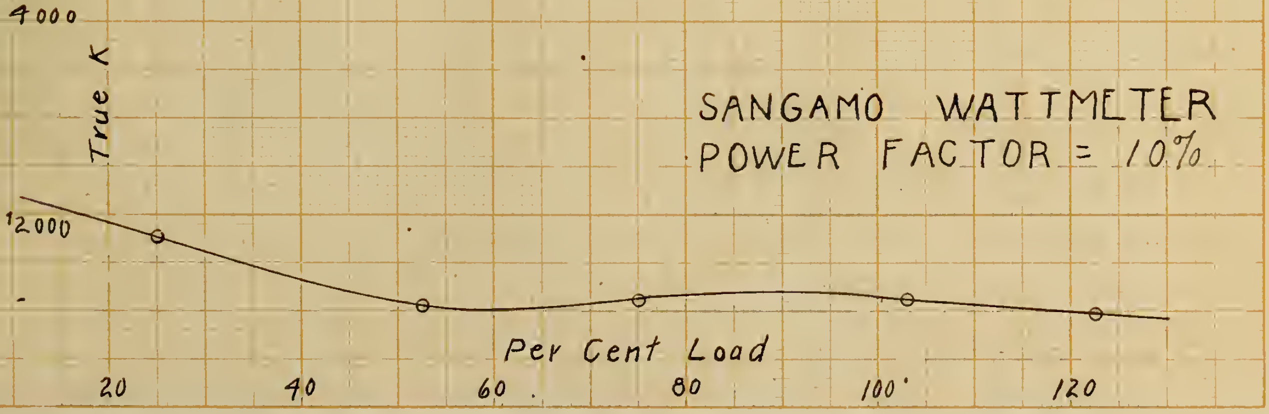

Per Cent Load
0
20
40
60
80
100
120
Per Cent Error
80
160
8000
6000
4000
2000
True K
SANGAMO WATTMETER
POWER FACTOR = 60%
Per Cent Load
20
40
60
80
100
120


SANGAMO WATTMETER
POWER FACTOR = 50%


Per Cent Load
0
20
40
60
80
100
120
80
16000
14000
Per Cent Error
80
12000
160
10000
True K
240
8000
320
6000
4000
2000
SANGAMO WATTMETER
POWER FACTOR = 40%
Per Cent Load
20
40
60
80
100
120


Per Cent Load
0
20
40
60
80
100
120
Per Cent Error
80
160
SANGAMO WATTMETER
POWER FACTOR = 20%
8000
6000
4000
2000
True K
Per Cent Load
20
40
60
80
100
120




SANGAMO WATTMETER
POWER FACTOR = 10%

U OF I S S FORM

SANGAMO MERCURY WATTMETER.

Calibration P.F.=100 %. Meter K.=3600.

Time in Sec.	Rev. of Disc.	I	E	W	K	Error	% Error	% Load I.	% P.F
145.2	9	2.42	110	265	4275	-675	-18.75	24.2	100
144.	9	2.52	110	265	4235	-635	-17.62	25.2	100
123.6	18	4.95	110	573	3940	-340	- 9.45	49.5	100
123.	18	4.91	110	573	3920	-320	-8.80	49.1	100
80	18	7.51	110	863	3840	-240	-6.66	75.1	100
78.8	18	7.71	110	895	3920	-320	-8.80	77.1	100
60	18	9.85	110	1134	3780	-180	-5.00	98.5	100
60	18	9.8	110	1129	3760	-160	-4.45	98.0	100
47.6	18	12.5	110	1373	3630	- 30	- .83	125.	100
47.6	18	12.8	110	1378	3640	- 40	-1.1	128	100

SANGAMO MERCURY WATTMETER.

Power Factor=90 %. Meter K.=3600.

Time in Sec.	Rev. of Disc.	I	E	W	% P.F.	K	Errors	% Errors	% Load I
19.9	9	2.52	110	245.5	89.6	5430	-1830	-50.8	25.2
96.5	9	5.07	110	510.	91.4	5475	-1875	-52.2	50.7
64.9	9	7.66	110	761.	90.3	5480	-1880	-52.3	76.6
59.5	9	10.15	110	1012.5	90.8	6690	-3090	=86	101.5
50.	9	12.	110	1195.	90.5	6650	-3050	-84.8	120.

SANGAMO MERCURY WATTMETER.

Power Factor=80.%　　　　Meter K=3600.

Time in Sec.	Rev. of Disc.	I	E	W	% P.F.	K	Error	% Error	% Load I-
108	4	2.64	110	231.	79.7	6275	-2675	-74.5	26.4
127.5	9	5.1	110	445.5	79.25	6330	-2730	-76	51.0
75.5	9	7.61	110	659.5	79.	5540	-1940	-54	76.1
59.7	9	10.2	110	885.	79.	5875	-2275	-63	102.
44.	9	12.8	110	1140.5	80.6	5580	-1980	-50	128.

SANGAMO MERCURY WATTMETER.

Power factor=70% K=3600.

Time in Sec.	Rev. of Disc	I	E	W	% P.F.	K	Error	% Error	% Load I
111.5	3	2.64	110	200	69	7435	-3835	-106.5	26.4
66.4	4	5.1	110	395	70.5	6550	-2950	- 82.	51.0
60.8	6	7.52	110	573	69.4	5810	-2210	- 61.4	75.2
41.5	6	10.15	110	776	69.5	5370	-1770	- 49.2	101.
31.5	6	12.5	110	955	69.4	5013	-1413	- 39.3	125.

SANGAMO MERCURY WATTMETER.

Power factor=60 %. Meter K=3600.

Time in Sec.	Rev. of Disc.	I	E	W	% P.F.	K	Error	% Error	% Load I
99	2	2.64	110	177	60.8	8750	-5150	-143	26.4
60.2	3	5.0	110	331	60.2	6615	-3015	- 83.7	50.
68.7	6	7.66	110	513	60.8	5865	-2265	- 63.	76.6
54.0	6	9.9	110	647.5	59.5	5820	-2220	- 61.7	99.0
39.5	6	12.5	110	825.0	60.	5430	-1830	- 50.9	125.0

SANGAMO MERCURY WATTMETER.

Power factor=50%. Meter K=3600.

Time in Sec.	Rev. of Disc.	I	E	W	% P.F.	K	Error	% Error	% Load I
55	1	2.96	110	161.5	49.65	8880	-5280	- 146.5	29.6
91.8	2	5.11	110	287.	51.0	13180	-9580	- 261	51.1
59.8	2	7.46	110	407.5	49.7	12200	-8600	-239	74.6
41.7	2	10.	110	552.	50.2	11500	-7900	- 219.5	100
68.7	9	12.8	110	708.	50.35	5413	-1813	- 50.4	128

SANGAMO MERCURY WATTMETER.

Power factor=40%   Meter K=3600

Time in Sec.	Rev. of Disc.	I	E	W	% P.F.	K	Error	% Error	% Load I
121.3	1	2.74	110	123	40.7	14900	-11320	-316.5	27.4
89.2	2	5.1	110	223.5	39.9	9990	- 6390	-177.5	51.
83.4	3	7.52	110	328	39.7	9112	-5512	-153.0	75.2
72.5	5	10.25	110	455.5	40.45	6625	-3025	- 84.1	102.5
63	4	13.0	110	584.	40.75	9212	-5612	-155.7	130.0

SANGAMO MERCURY METER.

P. F.=30%. Meter K=3600.

Time in Sec.	Rev. of Disc.	I	E	W	P.F.	K	Error	% Error	% Load I
		2.52	110	90	31.				25.2
		5.1	110	172	30.6				51.
		7.52	110	248	30.				75.2
		9.7	110	320	30.				97.
89.1	1	12.6	110	415.5	30.0	3700	-100	2.78	126.

Note: The meter was just creeping backwards during the first four readings on this Power factor.

SANGAMO MERCURY WATTMETER.

Power factor=20 %. Meter K=3600.

Time in Sec.	Rev. of Disc.	I	E	W	% P. F.	K	Error	% Error	% Load I
78.2	1	2.42	110	54	20.25	4220	-620	- 17.2	24.2
46.1	1	5.19	110	116	20.3	5350	-1750	- 48.6	51.9
97.5	2	7.71	110	167	19.7	8225	-4625	-127.	77.1
44.	3	9.95	110	218	19.95	3180	-420	- 11.6	99.5
87.5	6	12.25	110	262.5	19.5	3830	-230	- 6.4	122.5

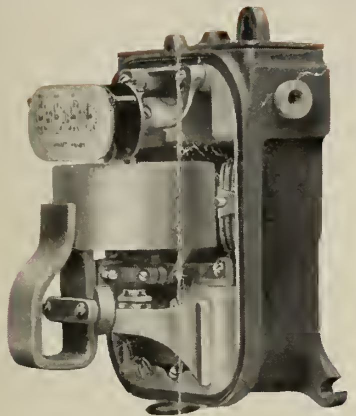
NOTE: Meter ran backwards.

SANGAMO MERCURY WATTMETER.

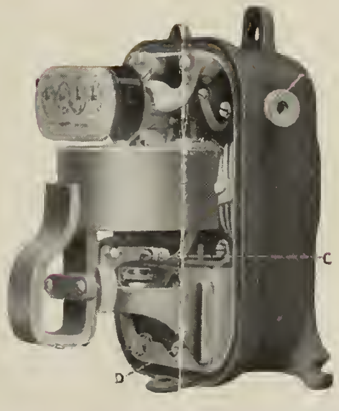
Power Factor=10% Meter K=3600.

Time in Sec.	Rev. of Disc.	I	E	W	% P.F.	K	Error	% Error	% Load I-
121.5	3	2.52	110	29	10.45	1760	1840	51	25.2
57.3	3	5.28	110	54	9.3	1030	2570	97.8	52.8
54.6	4	7.52	110	82.5	10.0	1123	2377	68.8	75.3
38.5	4	10.3	110	117.	10.3	1128	2372	68.55	103
39.8	5	12.25	110	125.	9.3	995	2505	72.43	122.5

NOTE: Meter ran backwards.



TYPE K FORM SAB WATTMETER
With Case Removed—Side View



TYPE K FORM SAA WATTMETER
With Case Removed—Side View

FORT WAYNE INDUCTION WATTMETER.

Type K, Single phase. Form S.B E. Class 2-110.

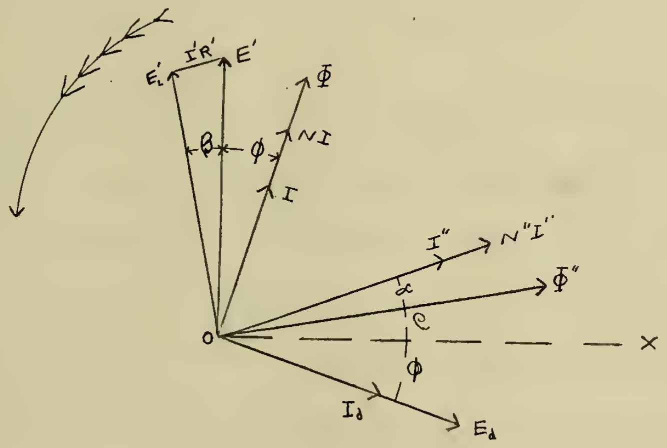
Amp. 10. Cycles 60. # 380220.

The motor element of the Fort Wayne Single Phase type K. induction wattmeter, consists of a stamped aluminum cup armature which rotates between a pair of current coils and a shunt coil. The current coils are two air cored coils of comparatively large wire of few turns connected in series; while the shunt coil consists of a great number of turns of fine wire mounted on a laminated iron core; the latter is highly inductive and its current lags approximately 90 degrees behind the impressed or line voltage. The current producing the series magnetic field will be in phase with the load current.

During a portion of each alternation of the current, the shunt coil helps the flux of one pole of the series field, opposing the other, and during another portion of the alternation it has the opposite effect; these reactions being combined in such a way as to give a general shifting of the lines of force in one direction, that is to produce a rotating field. This continuous motion of the field induces eddy currents in the aluminum disc, which react to produce rotation in the same manner as the rotor of an induction motor. The rotating field being a combination of the series and shunt fields will be proportional to the energy flowing in the circuit. If the load is inductive the current in the series coil will be more nearly in phase with the current in the shunt coil.

As less progression or shifting of the field occurs the rotation of the disc is lessened. It has been demonstrated that for correct registration on any power, exactly 90° phase relation between the shunt and series field must be maintained, otherwise the indications of the wattmeter will be in error on inductive loads.

The shunt winding is connected in circuit so that it measures the e.m.f. drop E' across the load. This winding consists of a large number of turns of fine wire and hence is highly inductive. E' causes a current I' through these windings. The e.m.f. E however, is cut down by the pressure drop $I' R'$, due to and in phase with the current I', so that only the e.m.f. E'_L is available for overcoming the counter induced pressure E_L of the windings. Because of the high inductance of the coil, I' lags nearly 90° behind E', the iron and copper loss tending to make the angle slightly less than the 90 degree relation which would hold if the circuit were purely inductive.



The current I'' passing through the n'' turns of the shunt

coil produces the magnetomotive force $n''I''$ tending to force the flux Φ'' which is thus proportional to E', through the iron core. This flux lags 90° behind the useful e.m.f. E'_L, and also lags behind the magnetomotive force $n''I''$ by the angle α, the hysteretic angle, whose value depends upon the magnetic density and upon the quality of the iron.

The series winding consisting of but a few turns of comparatively heavy wire has low self induction so the load current I is out of phase with the impressed electromotive force by only the small angle ϕ due to reactance in the outside circuit. The current I flowing through the n turns of the series winding, produces a magnetomotive force, nI tending to force the flux ϕ through the coil, and since this coil has an air magnetic circuit, Φ is in phase with n I.

Now the alternating flux Φ induces in the disc, an electromotive force E_d which is 90° behind the flux in phase, and this e.m.f produces in the disc a current I_d, which is in phase with it. As can be seen these eddy currents are proportional to and 90° behind I. Let the dotted line X represent the position that Φ'' would occupy if the shunt circuit were purely inductive, that is with no iron and copper loss. Then since X is perpendicular to E', and I_d to Φ, the angle between X and I_d is the same as that between E' and I, namely Φ.
Let the angle between the actual position of Φ'' and its possible position X, be ρ then $(\phi+\rho)$ is the actual angle between Φ'' and I_d.

The eddy current, I_d passing through the flux Φ'' is pushed sideways by this flux with a torque whose value given by $T = K I_d \Phi'' \cos(\phi+\rho)$. Now in order to measure correctly the energy consumed by the load it is evident that this driving torque ought to be directly proportional to the energy flowing in the circuit, that is T ought to equal $K E' I \cos\phi$. Actually, however, this is not the case, for while the angle between E' and I is ϕ, that between Φ'' and I_d, which are proportional to E' and I'' respectively is $(\phi + \rho)$. Hence the energy consumed will be equal to $K E' I \cos(\phi + \rho)$, the angle ρ being constant for a given load. For a discussion of the effect of this constant angle upon the accuracy of the meter, see "Discussion."

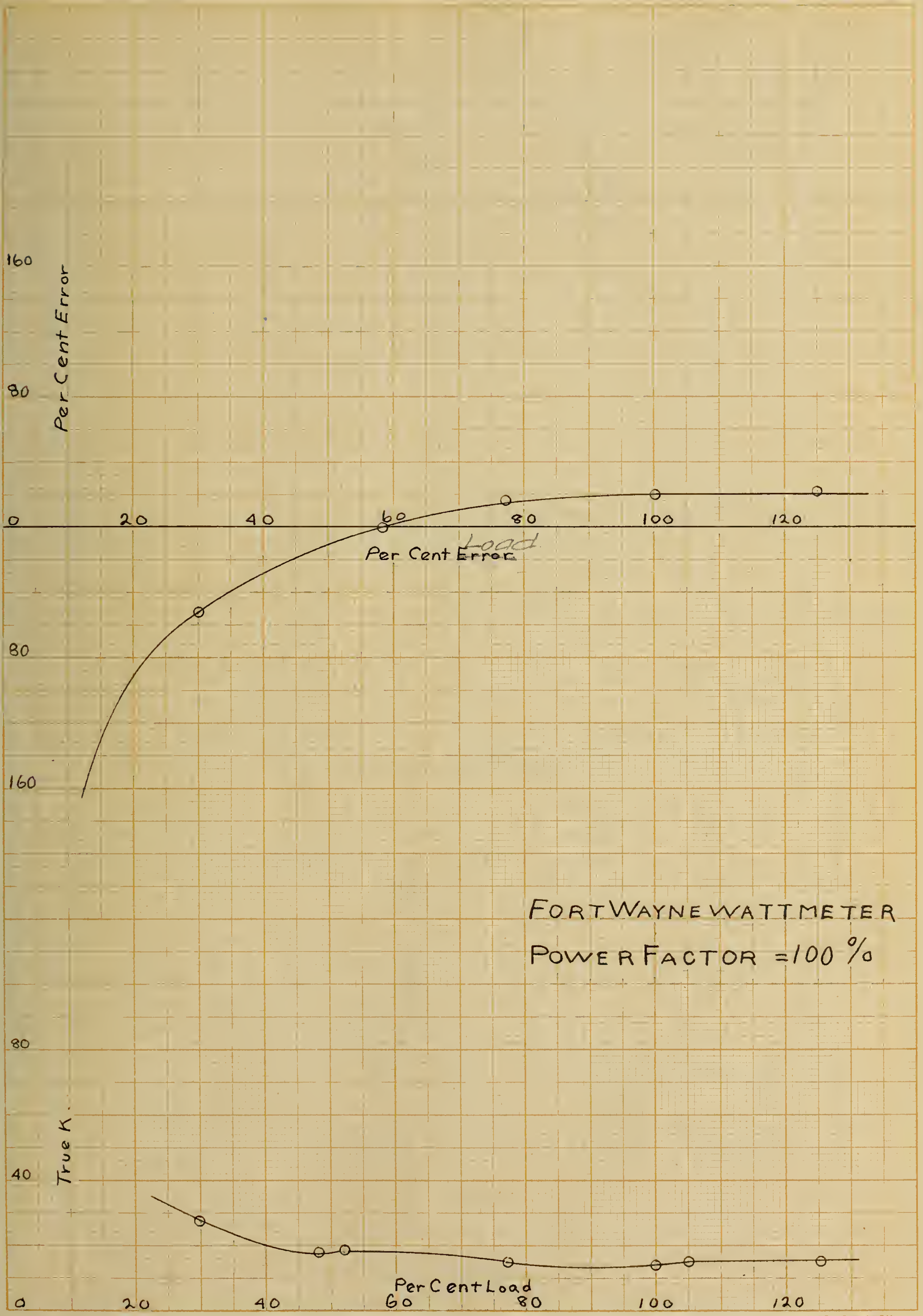
DISCUSSION OF CURVES OF FORT WAYNE DEDUCTION WATTMETER.

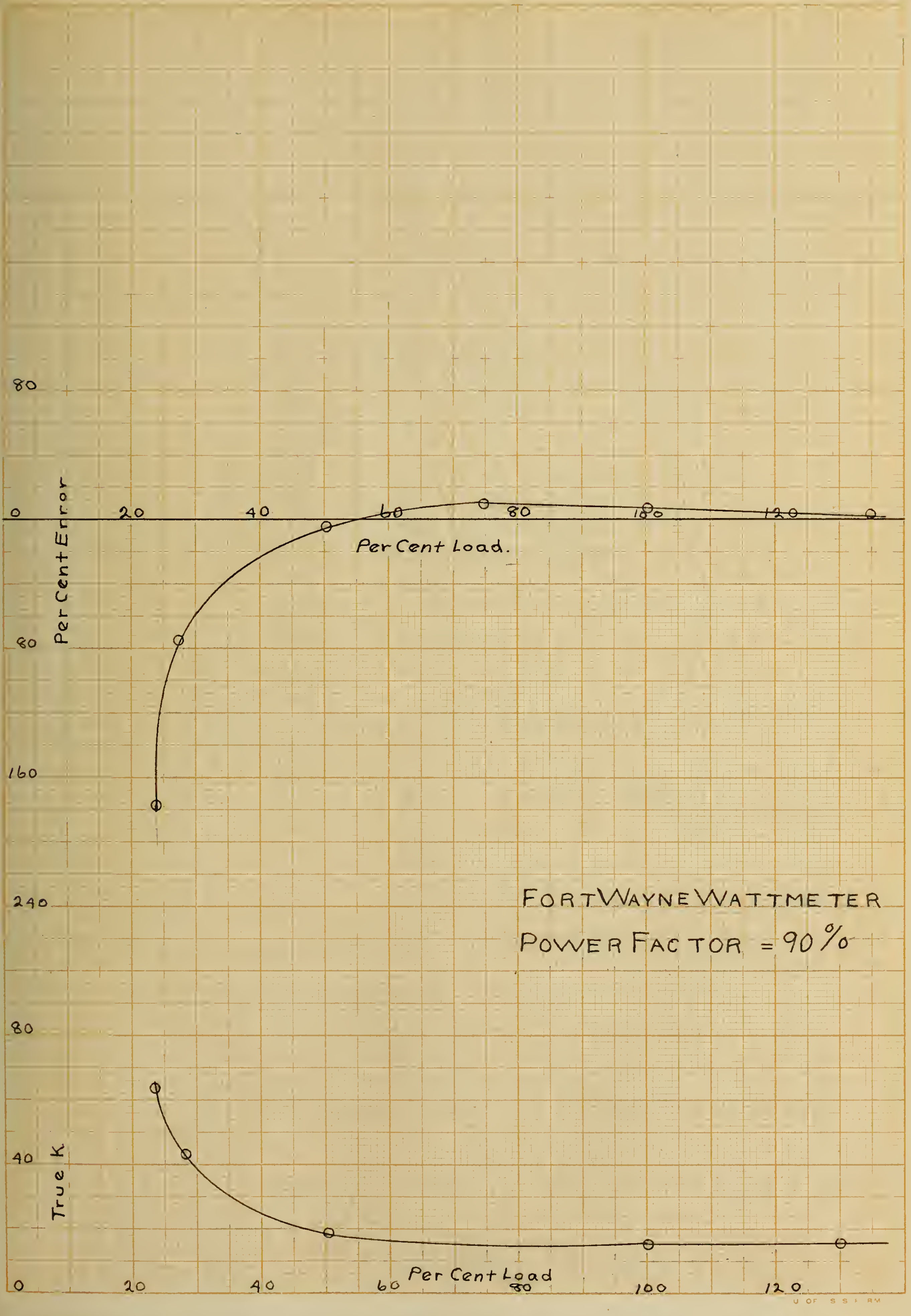
For 90 per cent power factor the per cent of error is greater for the loads below 50 per cent load current. Above this point the per cent of error is fairly constant. The per cent of error for 80 per cent power factor is very great for loads up to 60 per cent load, above this point the curve becomes nearly parallel with the zero error axis, thus showing that the per cent of error is practically a constant for all loads above 60 per cent load current.

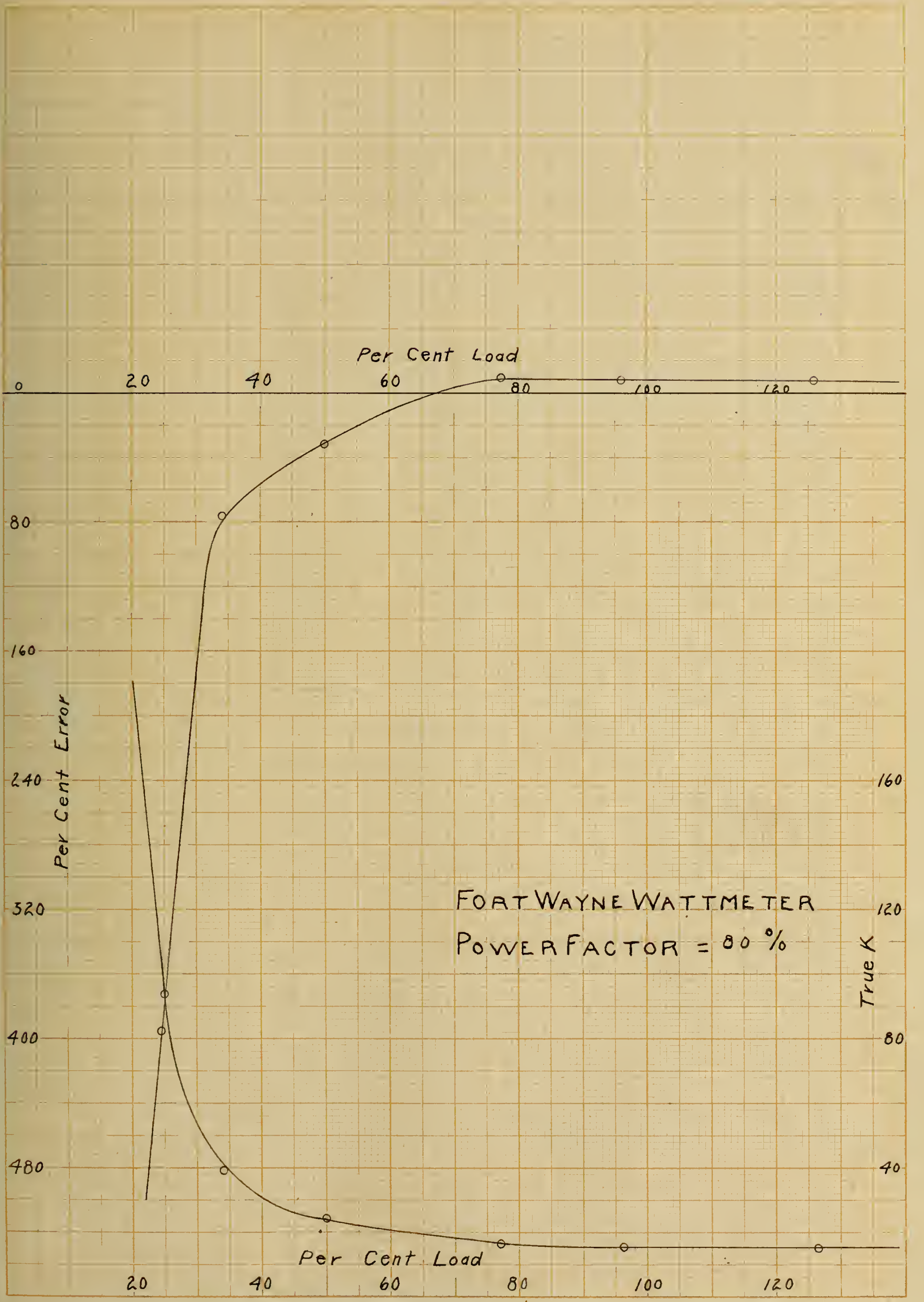
For 75 per cent power factor the curve of per cent error becomes nearly parallel with the zero error axis, above 60 per cent load; while below 60 per cent load the curve drops quite rapidly showing that the per cent of error is greater for the low loads. For 60 and 50 per cent power factor the curves show the error to be very great for the low values of current, but for the higher values the per cent of error becomes more nearly constant; all the time it approaches nearer to the zero axis. The per cent of error curves for 40 and 30 per cent power factor have developed the same dip as the curves for 10 and 20 per cent power factor of the Sangamo meter. From their inspection the error is practically the same for very low and high currents, but is greatest for the intermediate values of current.

For 20 per cent power factor the error curve drops off at once from the 125 per cent load. Thus for low loads the per cent error is so great that it will be impossible to use the meter.

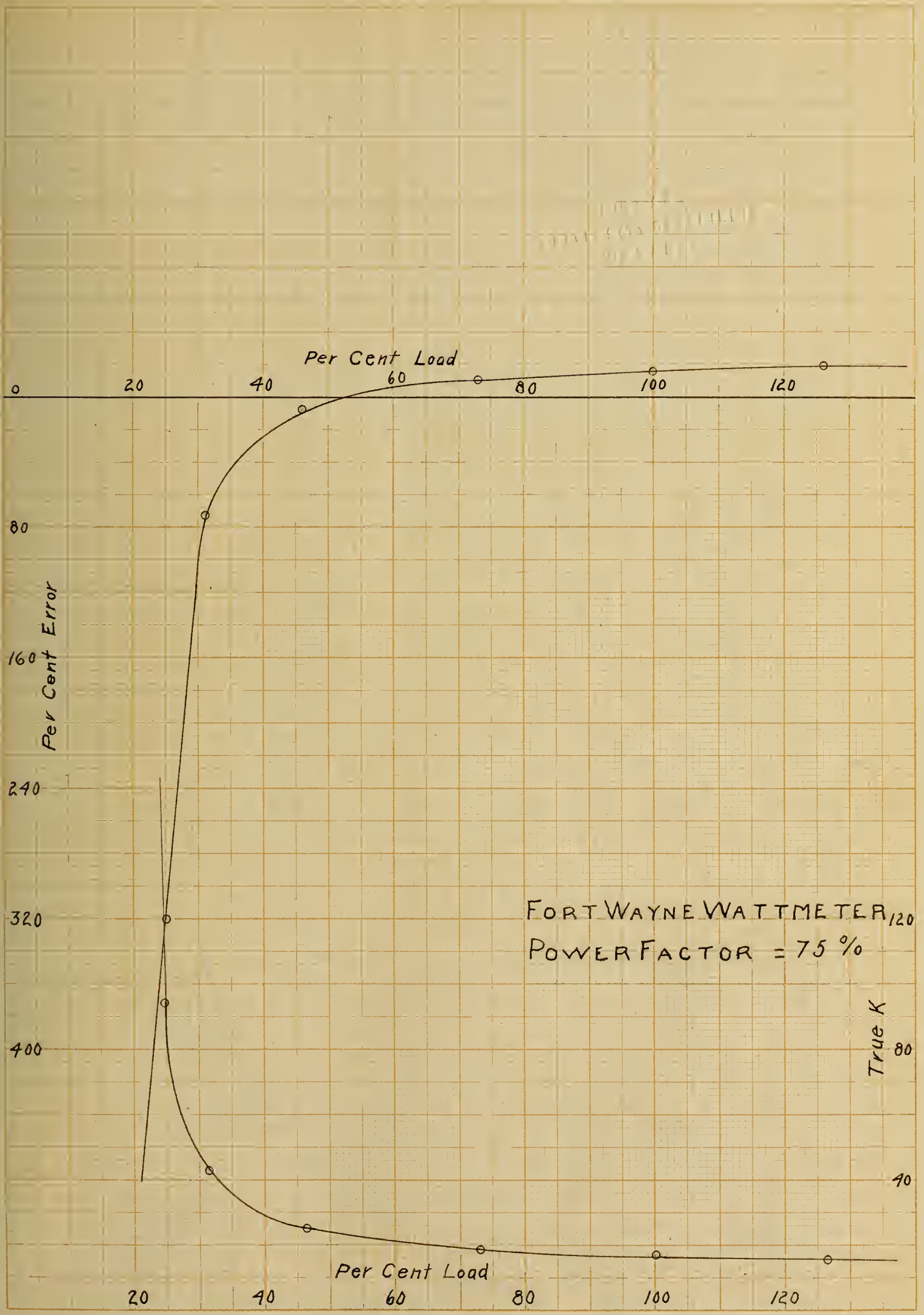
For 10 per cent power factor the meter crept so very slowly that it was impossible to get any readings of the revolutions of the disc. From the observation of this set of curves it is plainly seen that the meter operates very unsatisfactorily on low power factors. While on the higher power factors and higher values of load the meter operates very satisfactorily.


FORT WAYNE WATTMETER
POWER FACTOR = 100 %

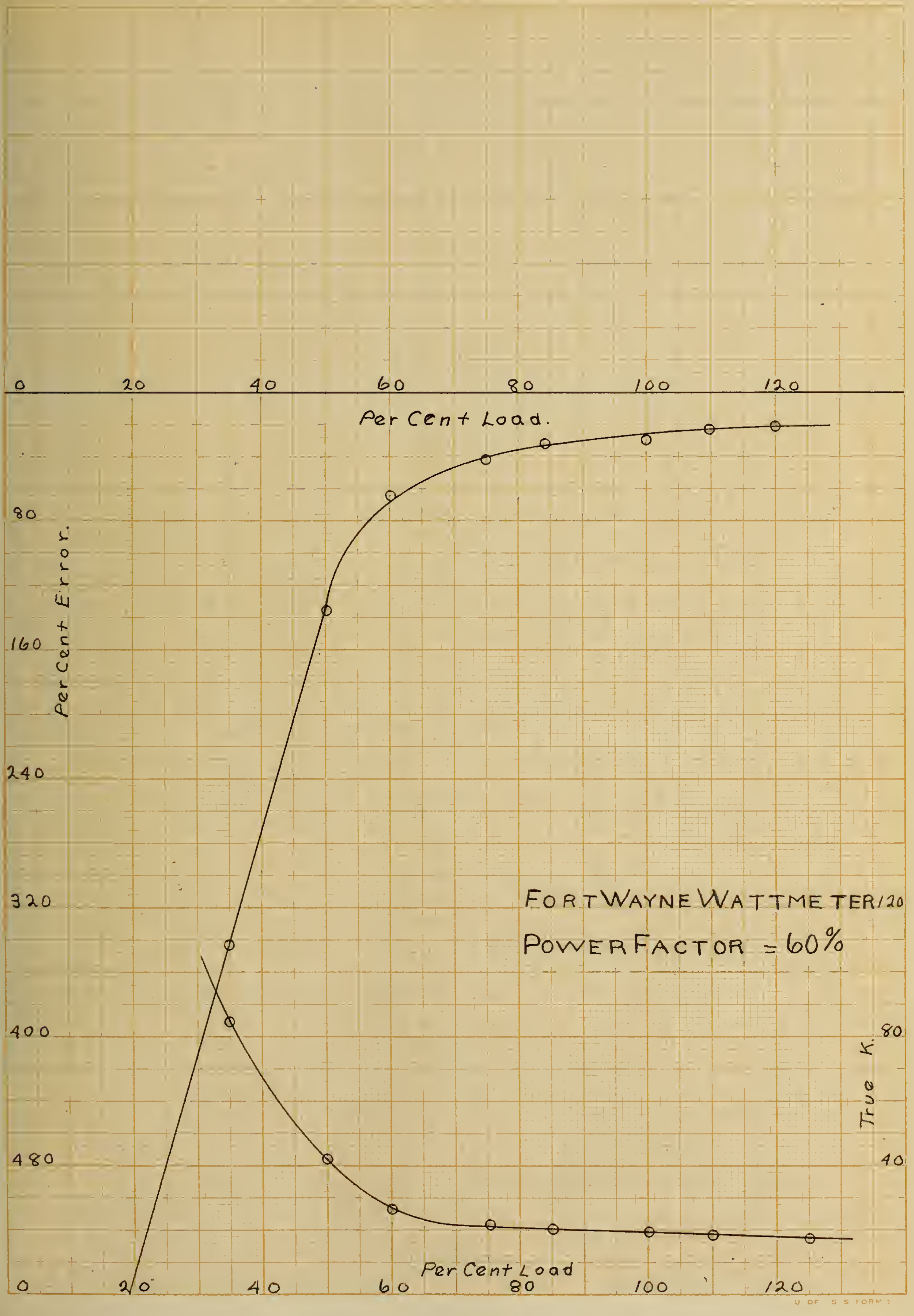

80
Per Cent Error
0
20
40
60
80
100
120
Per Cent Load.
80
160
240
Fort Wayne Wattmeter
Power Factor = 90%
80
40
True K
0
20
40
60
Per Cent Load
80
100
120


Per Cent Load
0
20
40
60
80
100
120
80
160
240
320
400
480
Per Cent Error
FORT WAYNE WATTMETER
POWER FACTOR = 80 %
160
120
True K
80
40
Per Cent Load
20
40
60
80
100
120

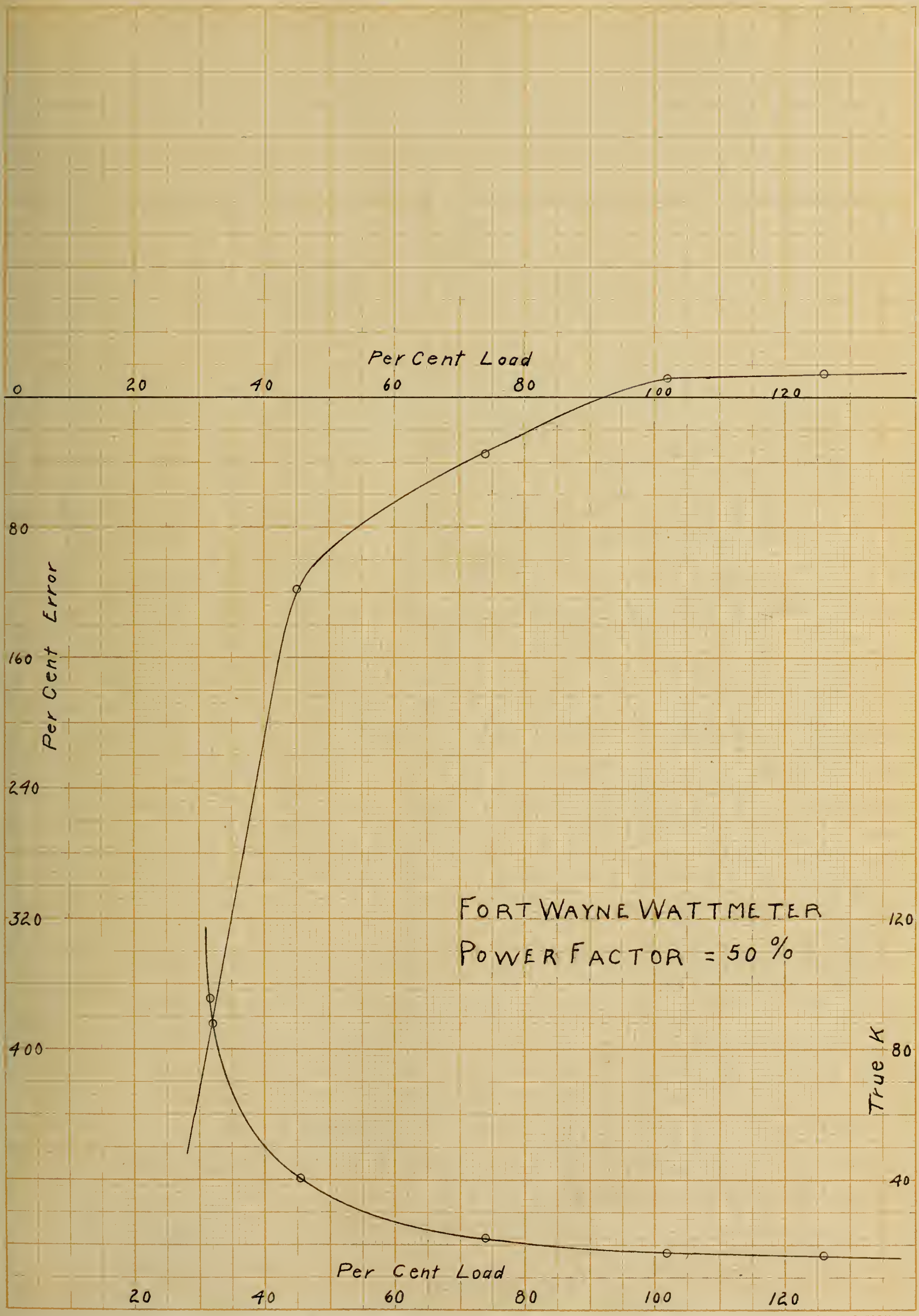
U OF I S S FORM

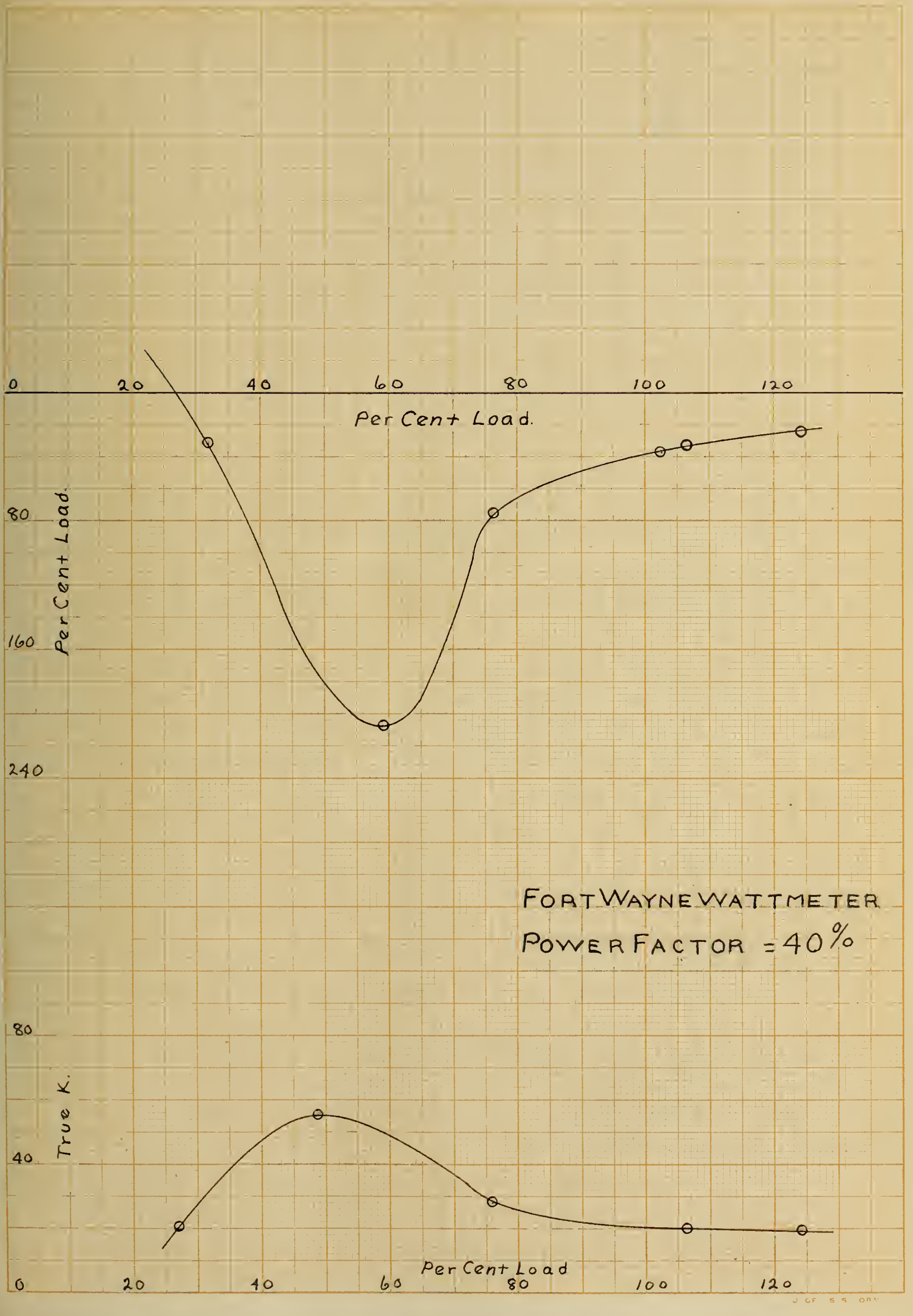

Per Cent Load
0
20
40
60
80
100
120
80
160
240
320
400
Per Cent Error
Fort Wayne Wattmeter
Power Factor = 75 %
120
80
40
True K
Per Cent Load
20
40
60
80
100
120

[illegible]

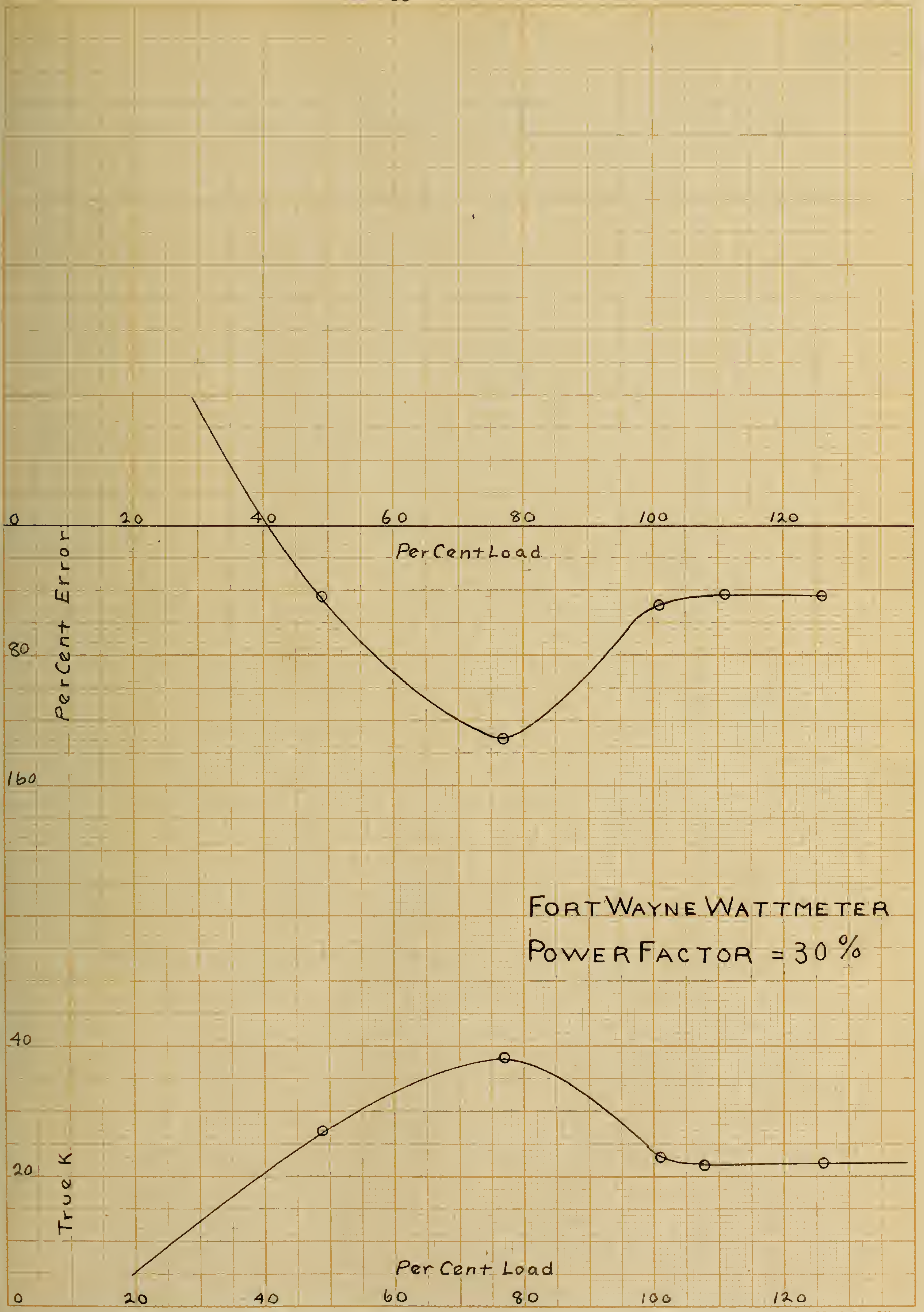

0
20
40
60
80
100
120
Per Cent Load.
80
160
240
320
400
480
Per Cent Error.
FortWayne Wattmeter 120
Power Factor = 60%
80
40
True K.
0
20
40
60
80
100
120
Per Cent Load

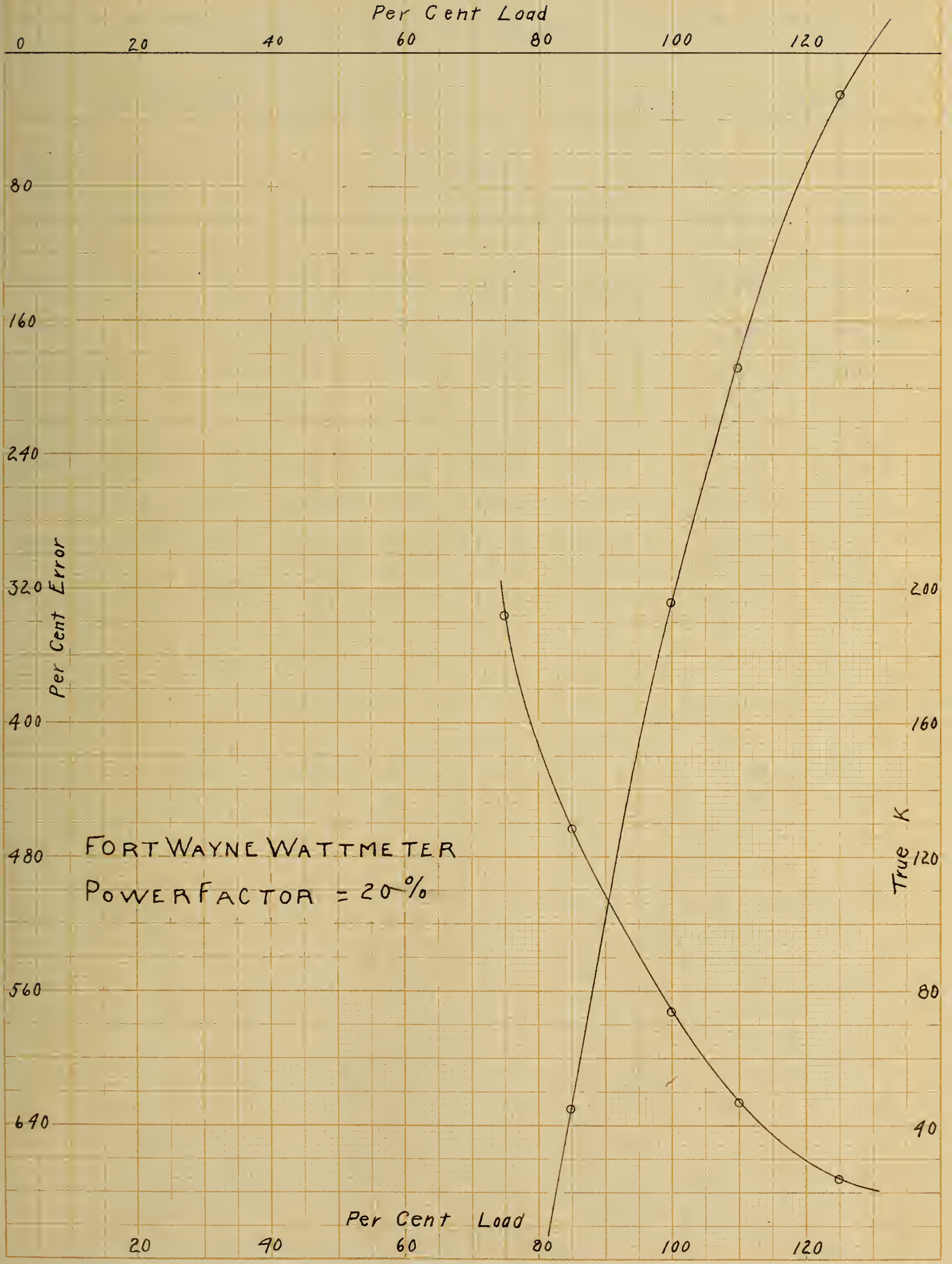
U OF S S FORM 3


Per Cent Load
0
20
40
60
80
100
120
80
160
240
320
400
Per Cent Error
FORT WAYNE WATTMETER
POWER FACTOR = 50 %
120
80
40
True K
Per Cent Load
20
40
60
80
100
120



FORT WAYNE WATTMETER
POWER FACTOR = 40%


0
20
40
60
80
100
120
Per Cent Load
Per Cent Error
80
160
Fort Wayne Wattmeter
Power Factor = 30 %
40
20
True K
Per Cent Load
0
20
40
60
80
100
120



FORT WAYNE WATTMETER

POWER FACTOR = 20 %

FORT WAYNE INDUCTION WATTMETER.

Calibration or P.F.=100 %. Meter Constant=18.

Time in Sec.	Rev. of Disc.	I	E	W	Comp. Const.	Error	% Error	% Load I
83.9	10	3	110	330	27.7	-9.65	-53.6	30
53.8	18	4.81	110	520	17.7	.30	1.67	48.1
59	18	5.2	110	578	18.9	- .9	-5.0	52.
55.6	18	5.325	110	585	18.05	- .05	-.28	53.5
34.3	19	7.7	110	827	14.9	3.1	17.2	77.0
47	36	10	110	1105	14.4	3.6	20.0	100.
48.7	36	10.5	110	1110	15.0	3.0	16.65	105
52	48	12.6	109.5	1362	14.8	3.2	21.1	126.

FORT WAYNE INDUCTION WATTMETER.

Power factor =90 %. Meter K=18

Time in Sec.	Rev. of Disc	I	E	W	% P.F.	K	Error	% Error	% Load I
26.4	1	2.42	110	240	90.2	63.8	-45.8	-251.5	24.2
125.5	8	2.75	110	272.5	90.4	42.8	-24.8	-137.5	27.5
69.3	18	4.98	110	497.5	90.7	18.6	- .60	- 6.4	49.8
41.5	18	7.52	110	737.5	89.35	17.	1.0	5.5	75.2
27.5	18	10.0	110	993.5	90.25	15.15	2.85	15.8	100.
34.5	30	13.0	110	1292.5	90.55	15	3.0	16.4	130

FORT WAYNE INDUCTION WATTMETER.

Power Factor=80% Meter K=18

Time	Rev.	I	E	W	% P.F.	C	Error	% Error	% Load I
4.5	1	2.42	110	210	79	94.5	-86.5	-480	24.2
104	8	3.39	110	297	79.7	38.6	-20.6	-114.3	33.9
44.25	8	5.0	110	240	80	24.35	- 6.35	- 35.25	50.
45.	18	7.735	110	685	80.45	17.1	+ .9	+ 5.	77.3
33.1	18	9.65	110	865	81.45	15.87	.13	11.8	96.5
33.7	24	12.65	110	1125	80.9	15.82	.18	12.1	126.5

FORT WAYNE INDUCTION WATTMETER.

Power Factor=75 %. Meter K=18

Time in Sec.	Rev. of Disc.	I	E	W	% P.F.	K	Error	% Error	% Load I
91.6	2	2.52	110	205	74.	94	-76	-420	25.2
124.2	8	3.125	110	260	75.5	43.25	-25.25	-140.3	31.20
119	18	4.66	110	382.5	74.65	25.35	- 7.35	- 40.8	46.6
55.7	18	7.32	110	610	75.8	18.85	- .85	- 4.72	73.2
37.	18	10.05	110.2	840	75.65	17.3	.7	3.88	100.5
53.7	36	12.65	109.6	1035	74.6	15.45	2.55	14.17	126.5

FORT WAYNE DEDUCTION WATTMETER.

Power factor=60% Meter K=18

Time in Sec.	Rev. of Disc	I	E	W	P.F.	K	Error	% Error	% Load I
142.6	1	2.5	110	167	60.7	235.5	-217.5	-1205	25
73.4	2	3.5	110	230	60	84.25	- 66.25	- 367	35
64.2	5	5	110	330	60	42.4	- 24.4	- 135.5	50
53.8	8	6	110	400	60.7	26.9	- 8.9	- 49.5	60
55.	12	7.5	110	490	59.5	22.5	- 4.5	- 25	75
57	15	8.5	110	558	59.3	21.2	- 3.2	- 17.75	85
57	19	10	110	662	60	19.85	- 1.85	- 10.3	100
57	23	11	110	725	60	18.22	- .22	- 1.22	110
57	26	12.5	110	820	59.6	17.95	.05	.278	125

FORT WAYNE INDUCTION WATTMETER.

P.F.=50%　　　　Mater K=18

Time in Sec.	Rev. of Disc	I	E	W	% P.F.	K	Error	% Error	% Load I
110.7	2	3.2	110	172.5	49	95.5	-77.5	-429	32.
65.4	4	4.53	110	247.5	49.65	40.5	-22.5	-125	45.3
43.9	8	7.38	110	400	49.55	21.9	- 3.9	- 21.95	73.8
30.5	10	10.2	110	578	51.5	17.65	.35	1.95	102
43.2	18	12.6	110	688.5	49.6	16.55	1.45	8.05	126

FORT WAYNE WATTMETER.

Power factor=40%. Meter=18

Time in Sec.	Rev. of Disc.	I	E	W	% P.F.	K	Error	% Error	% Load I
Just creeps		2.42	110	95					24.2
143	1	3.20	110	140	39.8	20	-2	-11.1	32
155.5	6	4.91	110	217.5	40.2	54.6	-36.6	-203.2	49.1
68.6	8	7.66	110	335	40	28.75	-10.75	- 59.7	76.6
44.3	10	10.6	110	466.5	40.1	20.8	- 2.8	- 15.55	106
34.4	10	12.45	110	550	40.15	18.9	- 9	- 5.05	124.5

FORT WAYNE INDUCTION WATTMETER.

Power factor=30% .　　　　Meter K=18

Time in Sec.	Rev. of Disc.	I	E	W	% P.F.	K	Error	% Error	% Load I
Just creeps		2.3	109.5	109.5	31.6				23
166.6	1	4.9	110	160	30.7	26.7	- 8.7	48.	49
74.5	5	7.66	110	260	30.8	38.8	-20.8	115.5	76.6
68.5	10	10.1	110	342.5	30.75	23.	- 5	27.8	101
63.6	12	12.6	110	417.5	30.15	22.1	- 4.1	22.75	126

FoRT WAYNE INDUCTION WATTMETER.

Power factor=20%　　　　Meter K=18

Time in Sec.	Rev. of Disc	I	E	W	% P.F.	Comp. Cons.	Error	% Error	% Load I
116.4	1	7.5	110	165	20	192	-174	-967	75
68.4	1	8.5	110	187	20	128	-110	-612	85
67	3	10.0	110	220	20	73.7	- 55.7	-309	100
58	3	11.	110	243	20.1	47.	- 29.	-161	110
60.4	7	12.5	110	285	20.7	24.6	- 6.6	- 3.7	125

NOTE: The meter just crept on the loads up to 7.5 Amperes on this power factor.

Constant formula= $\frac{\text{Rev.X100C}}{\text{Sec.}}$ =Watts.

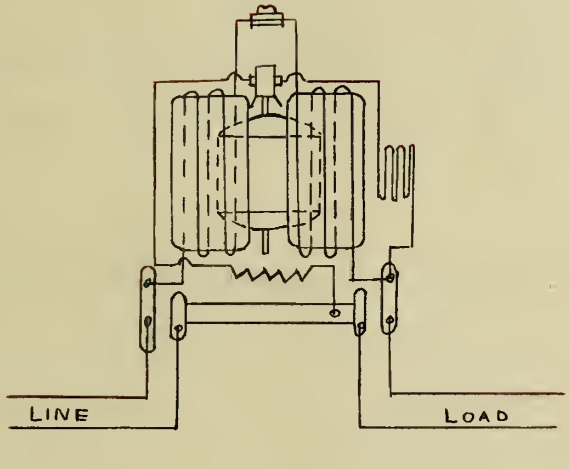


DIAGRAM
of
THOMSON RECORDING WATTMETER
TYPE M. CLASS 3-500 FORM JEN.
131623.

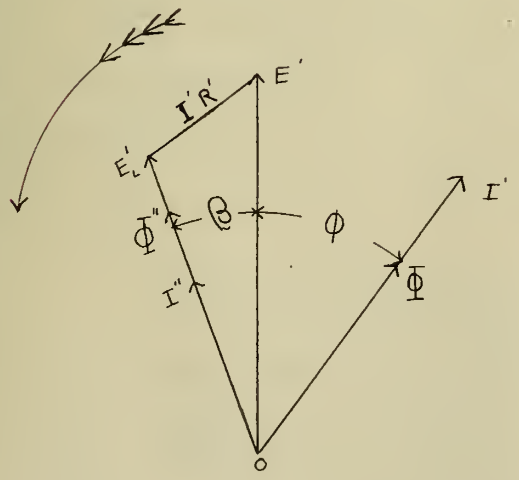
DISCUSSION OF THE THOMSON RECORDING WATTMETER.

For the commutator type of meter the Thomson Recording Wattmeter Type M, was used This meter is so adapted that either alternating or direct current, whether the former be inductive or non-inductive may be measured without change of calibration. This feature makes it especially suitable to the needs of power stations furnishing different kinds of current. The Thomson Type M meter in principle is a modification of the Siemen's dynamometer, the stationary coils of which are energized by the current flowing and the movable coils proportionately to the potential of the circuit in which the meter is put. There is no iron in the shunt or series field coils.

The armature spindle is supported on a removable jewel bearing; just above this bearing is the usual dampening disc which revolves between the poles of two permanent magnets. On the other end of the armature spindle is found the commutator which is made of silver, and the two copper brushes which bear on it are silver tipped. In the two wire meters the field coils are placed one on each side of the armature and are connected in series. In series with the armature is a resistance coil to regulate the flow of the current in the potential coil and also to reduce the fall of potential between the armature coils and commutation segments.

Meters of the motor class contain three essential elements; the motor element, the generator element; and the counting device. The motor element is the one which will be

considered. The power consumed by the meter is used in supplying the copper I R losses, in the motor windings the friction losses and in driving the generator. Thus the torque produced by the motor is proportional to the product of a current and a magnetic flux. Since there is no iron in the circuit, the flux is proportional to the current and therefore the torque is proportional to the currents flowing in the windings. Since one winding is connected across the mains its current is proportional to the pressure; the other winding is in series with the circuit, hence the product of the current values or the torque will be proportional to the power consumed by the load. Since there is no iron in the circuit there would be no effect due to hysteresis. Also the value of ϑ would be the same for the same values of load regardless of the power factor.



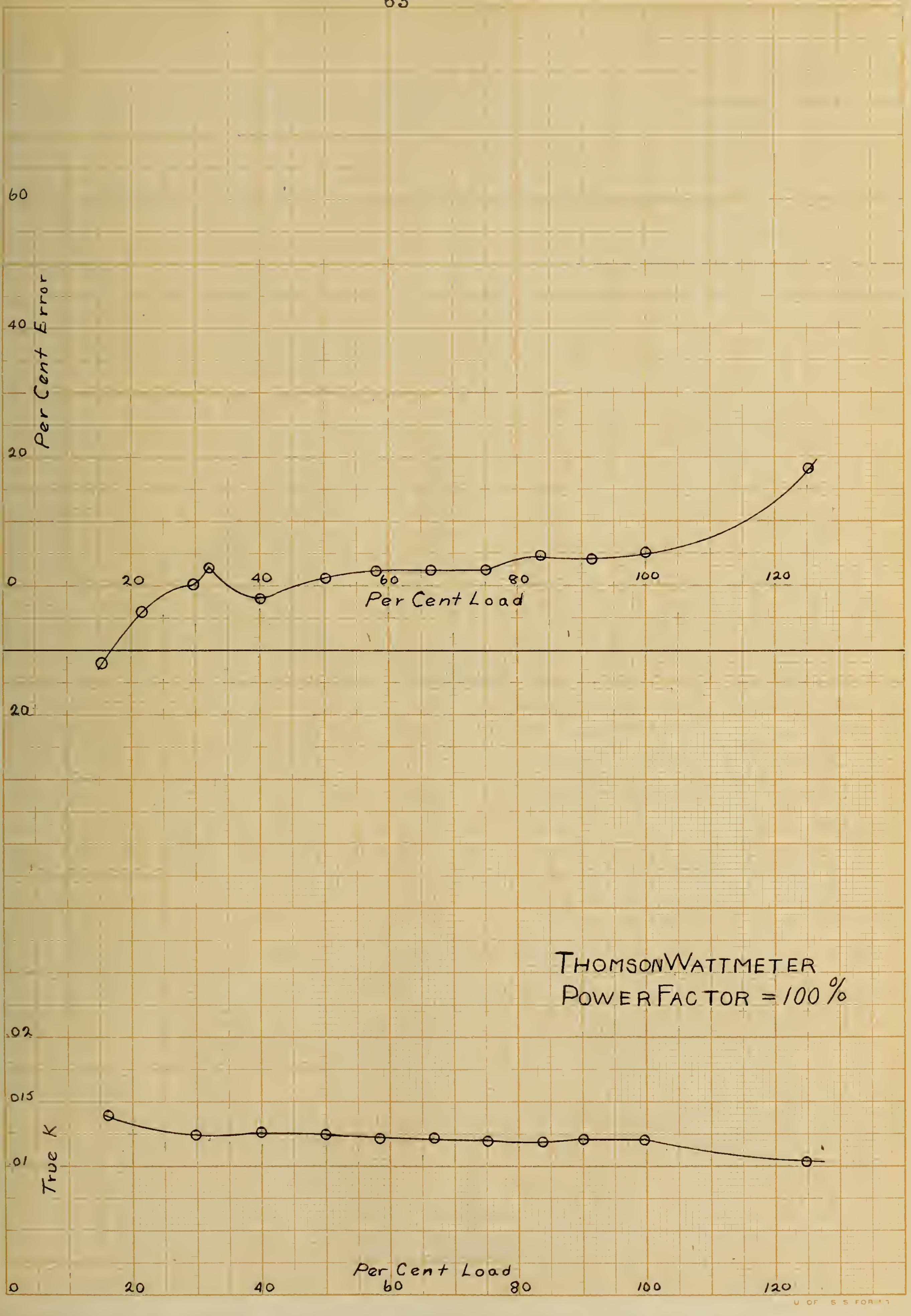
Referring to the vector diagram; E', the impressed pressure and E'_L the useful e.m.f. which differs from E', by the angle ϑ due to the I R drop in the windings. The flux Φ'' is in phase with E'_L , that is the flux produced by the shunt coil, w while the current I, in the series coil lags behind the impressed E' , by an angle ϕ , produces a flux Φ , which is in phase with it.

But the torque is equal to $KI\Phi''\cos(\phi+\beta)$. when B is constant for any given load. Now in order to correctly register the watts passing through the circuit the torque ought to equal $KI\Phi''\cos\phi$. The probable effect of this constant angle for different phase angles on the accuracy of the meter may be found under the General Discussion. This effect will probably account for the irregularities in accuracy at a given load on different power factors.

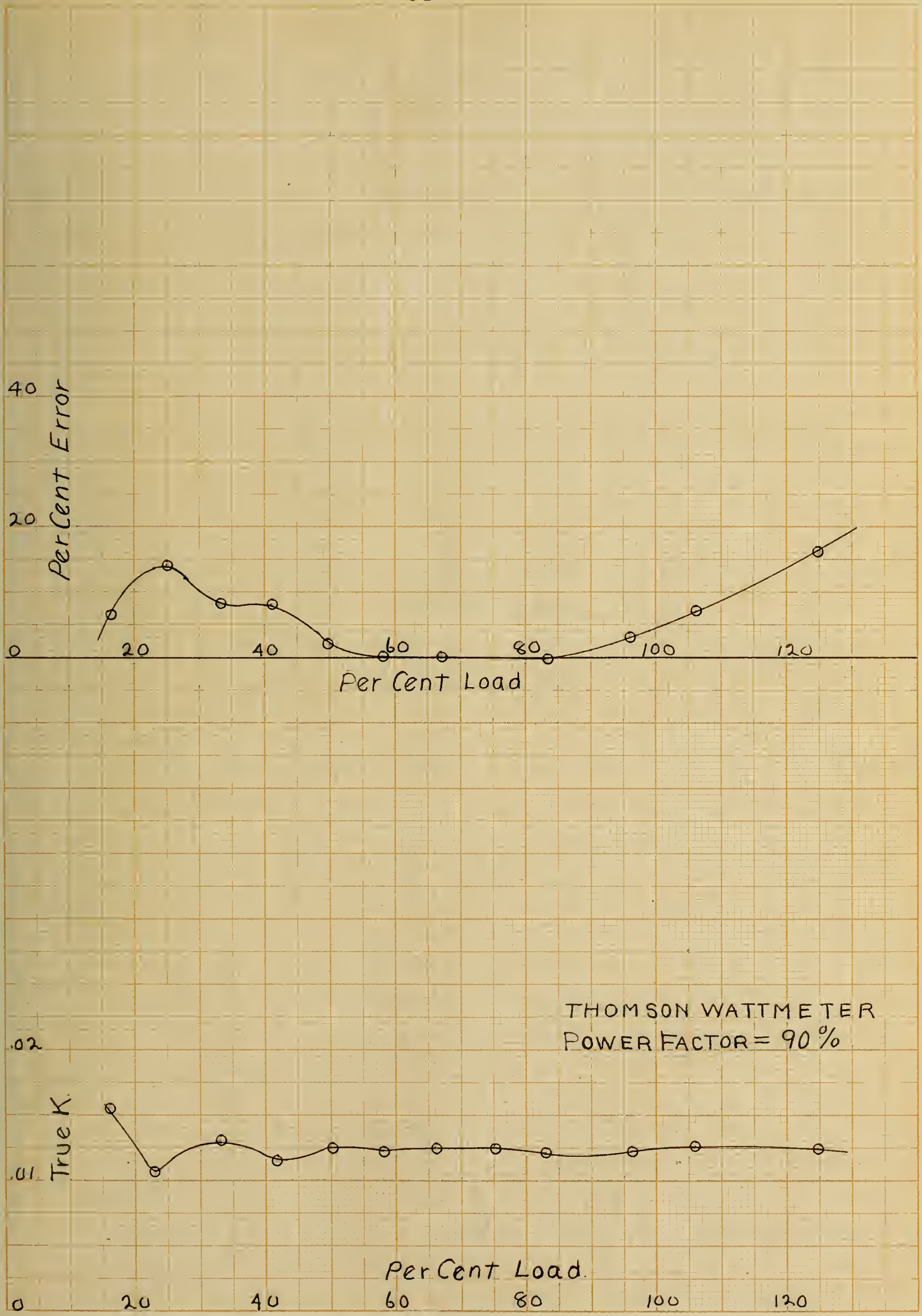
DISCUSSION OF CURVES FOR THOMSON RECORDING WATTMETER.

For 100 per cent power factor the error is negative for low loads crossing the zero line at about 50 per cent load, from there on it shows an uniformly increasing error on the positive side. The error is entirely positive except for intermediate points, where it is zero for 90 per cent power factor. The curve is very irregular for 80 per cent power factor, the average error being positive. The general shape of the curve being directly opposite to tht of the curve at 90 per cent power factor. The error for 70 per cent power factor is positive except for overloads when it becomes negative. The same is true for 60 per cent power factor.

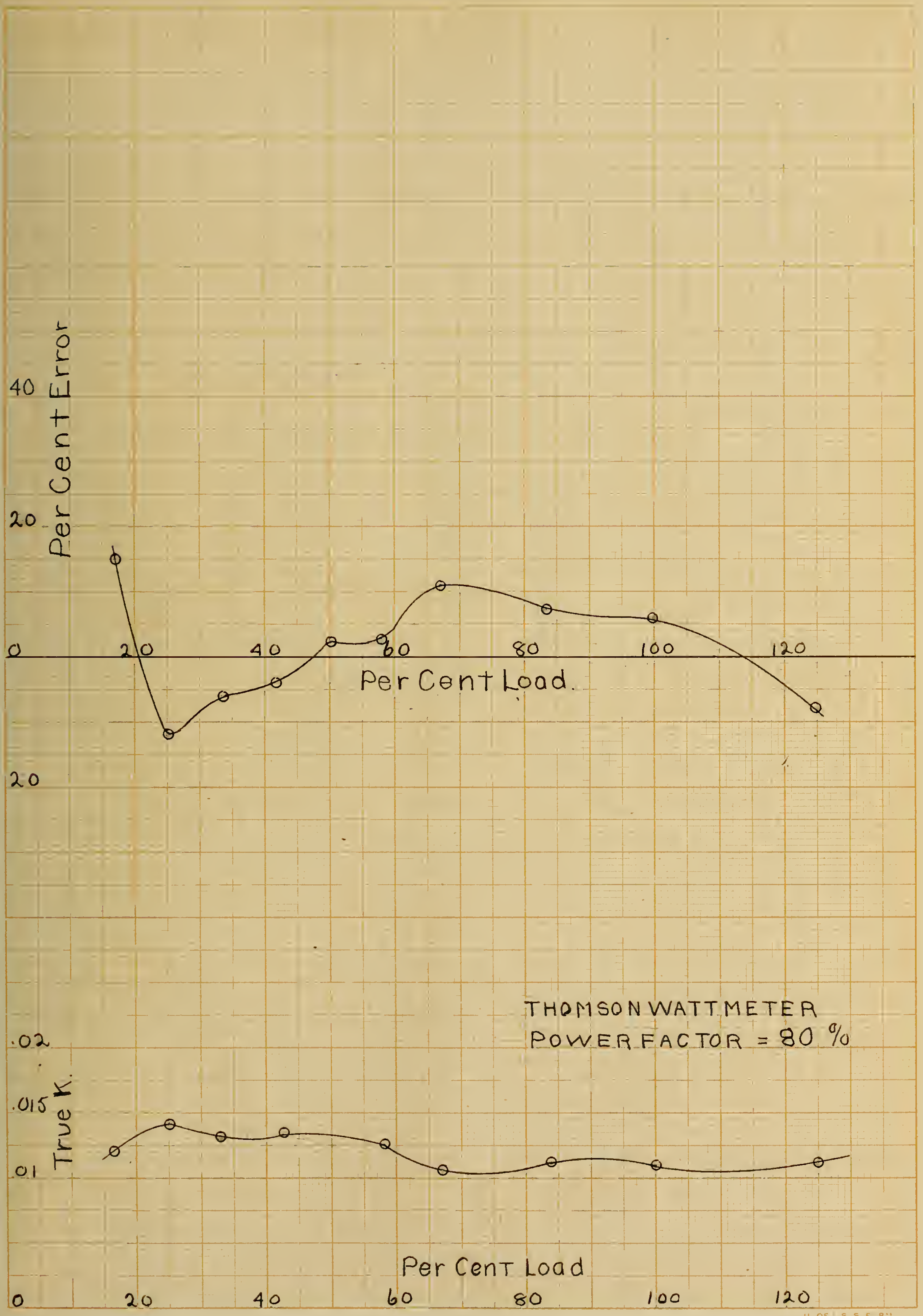
For the remaining per cent of power factors down to and including 10 per cent power factor the errors are entirely positive, gradually increasing in amount as the power factor decreases. The average error of the meter is a gradually increasing one as the power factor decreases. This is probably due to the increasing effect of the angle B on the torque angle as the phase angle decreases.



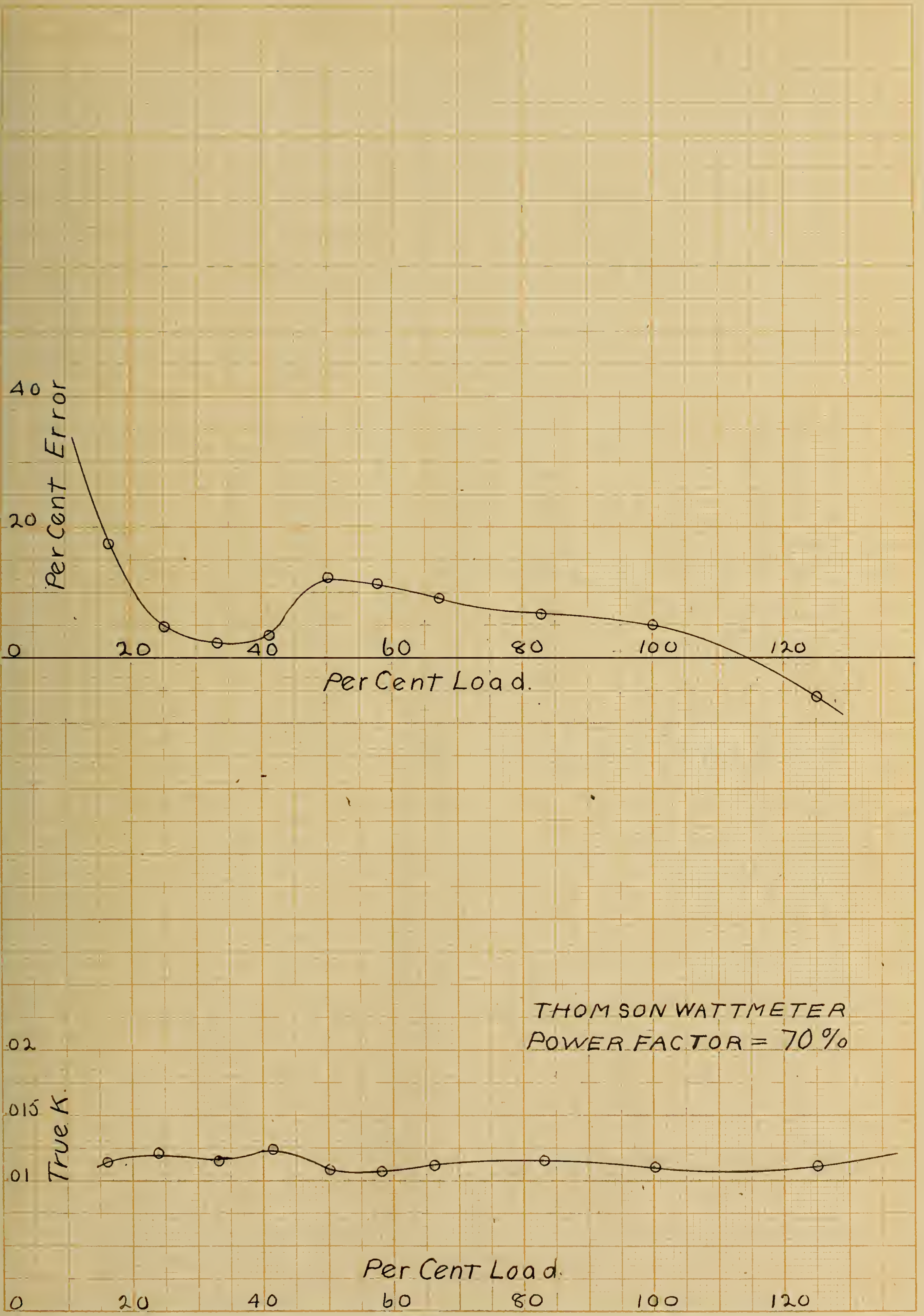
THOMSON WATTMETER
POWER FACTOR = 100 %

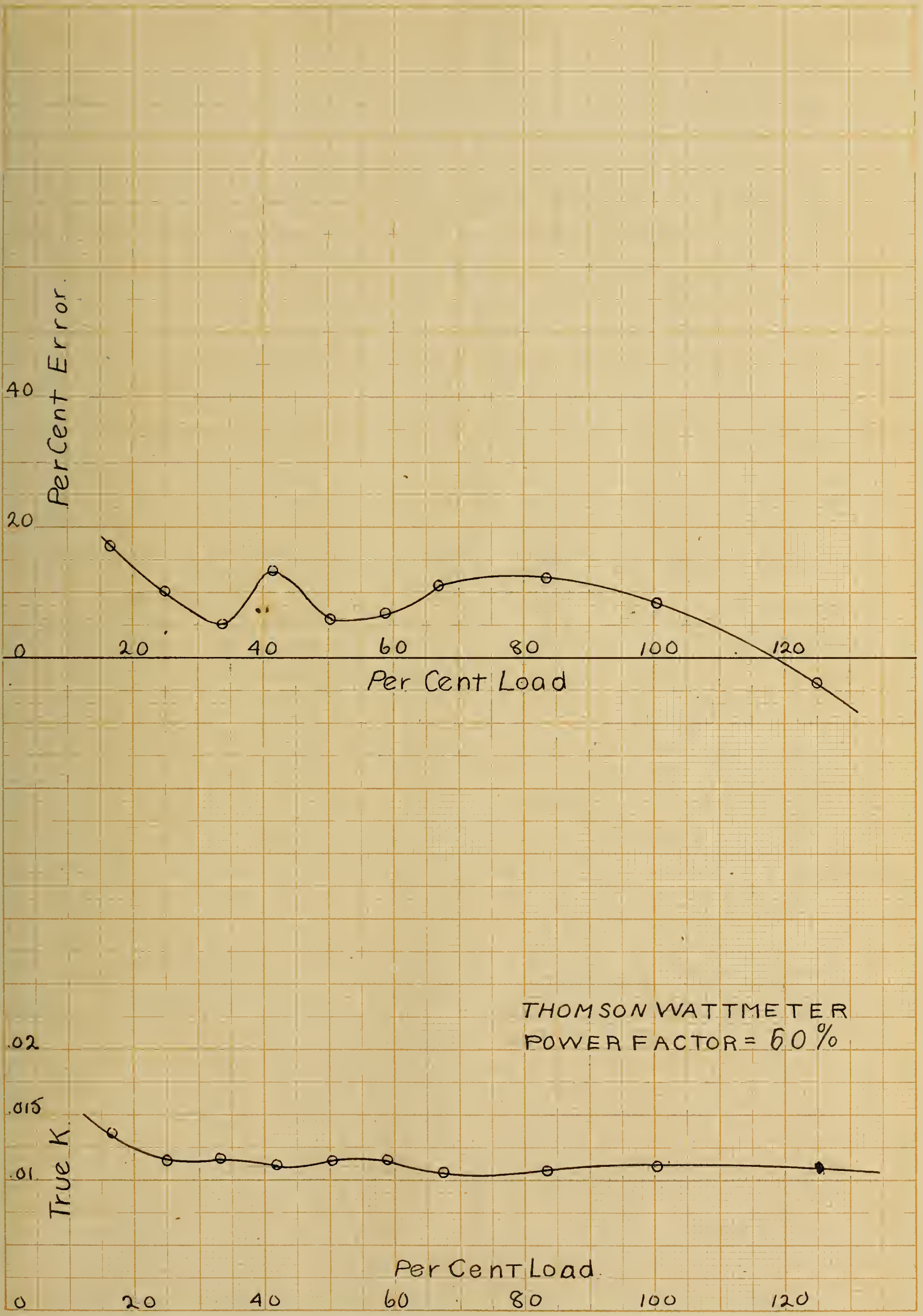


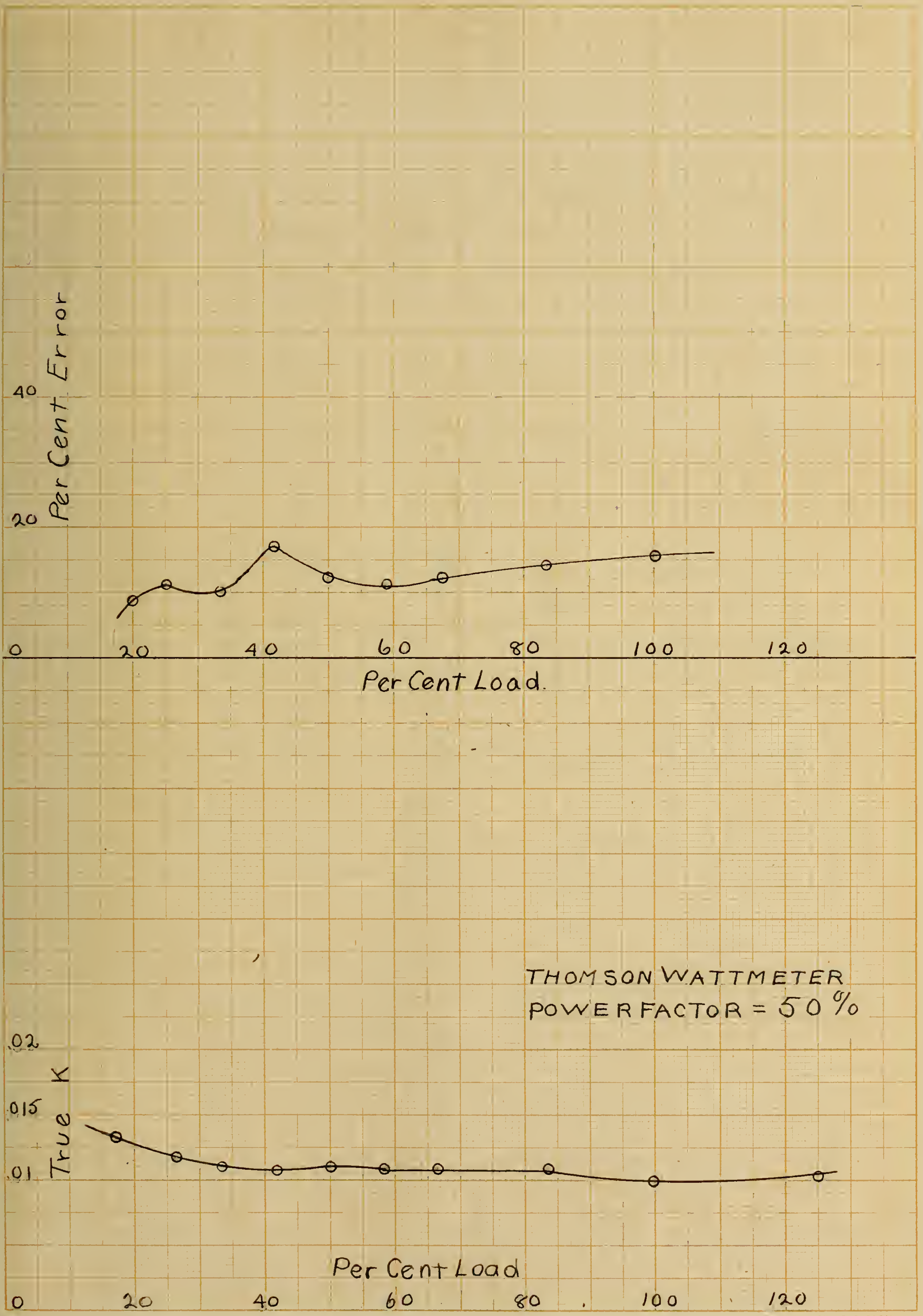
U OF I S S FORM 3



THOMSON WATTMETER
POWER FACTOR = 80 %

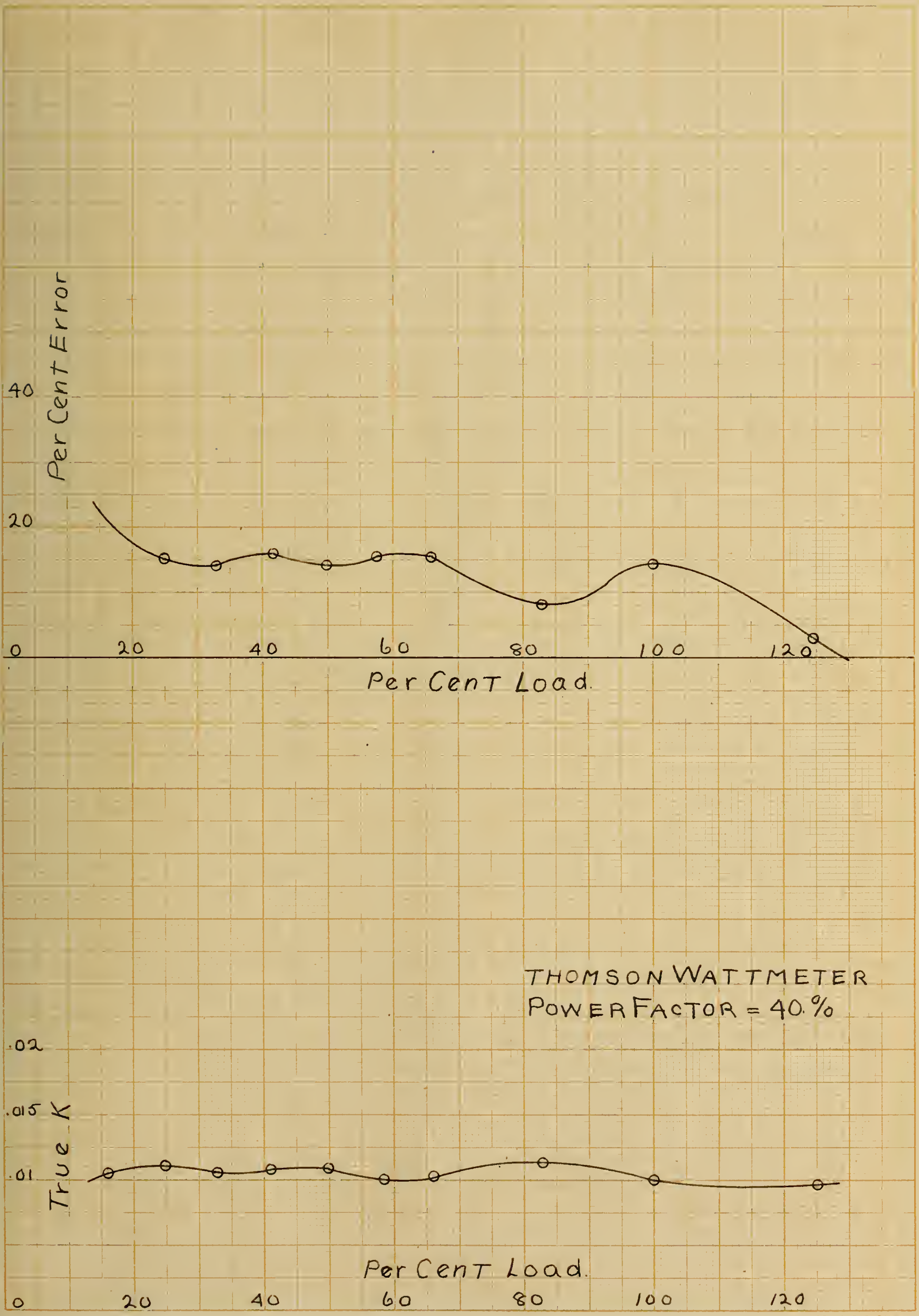

THOMSON WATTMETER
POWER FACTOR = 70%

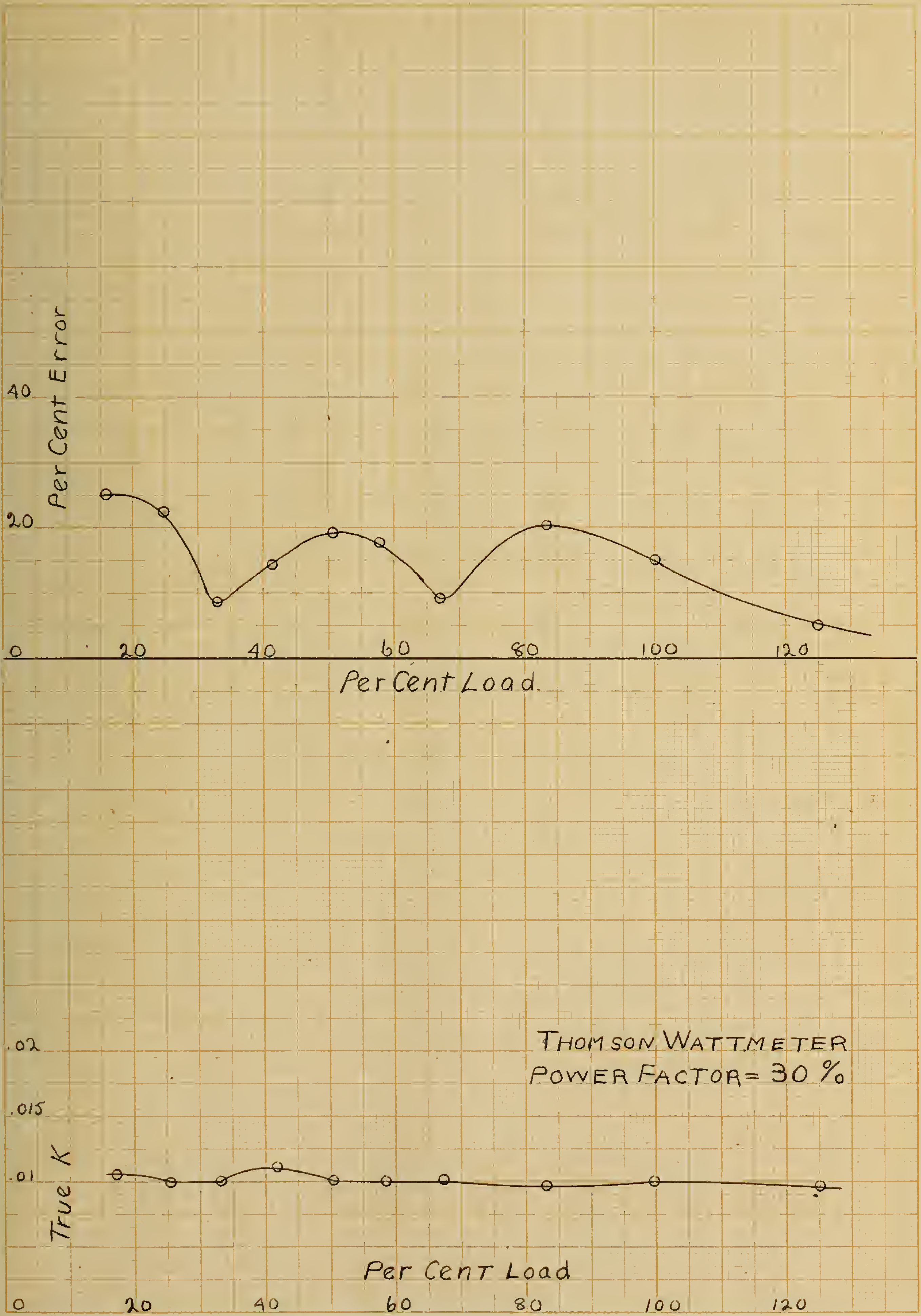

Per Cent Error.
40
20
0
20
40
60
80
100
120
Per Cent Load
THOMSON WATTMETER
POWER FACTOR = 60%
.02
.015
True K.
.01
Per Cent Load
0
20
40
60
80
100
120

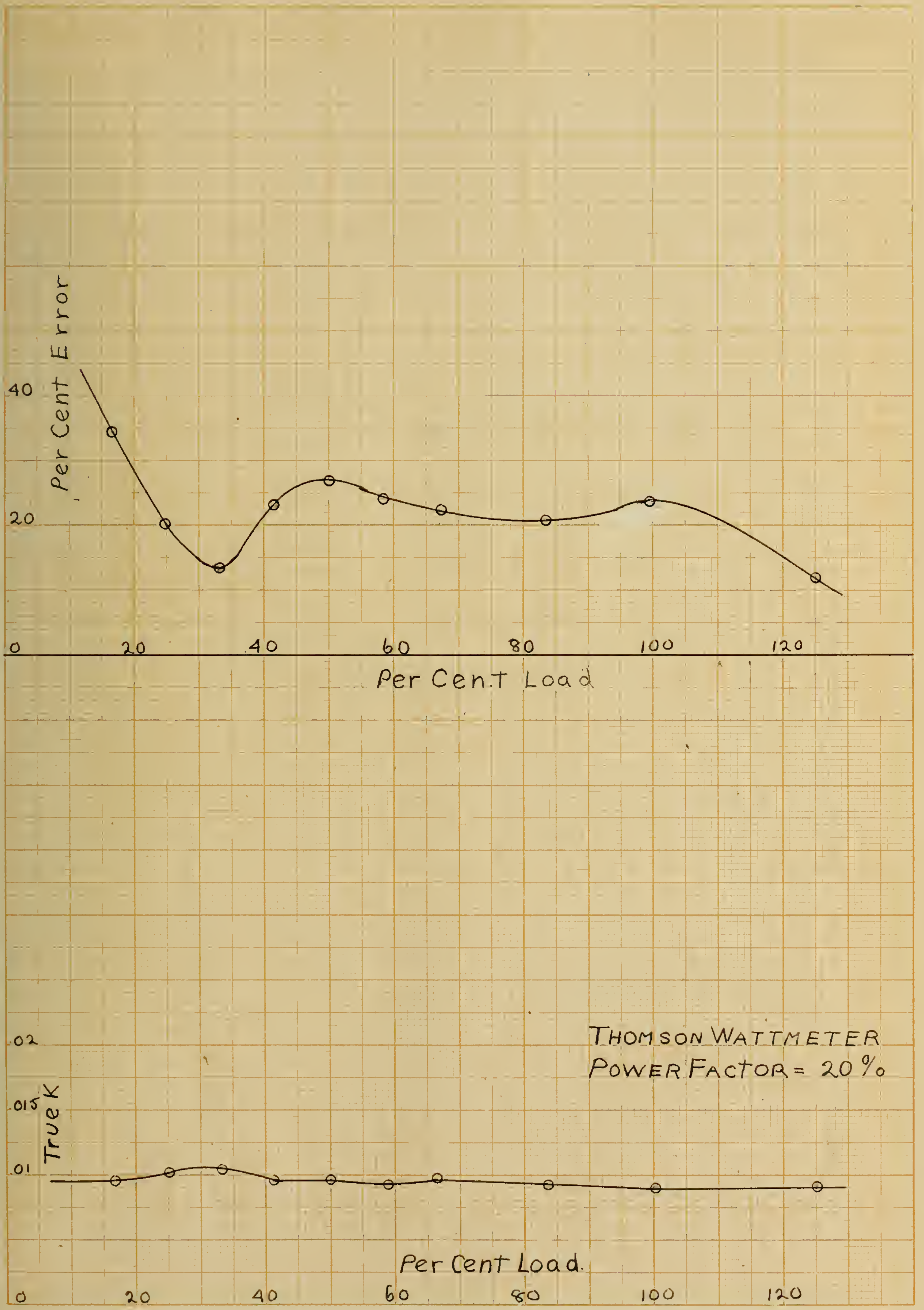


THOMSON WATTMETER
POWER FACTOR = 50 %

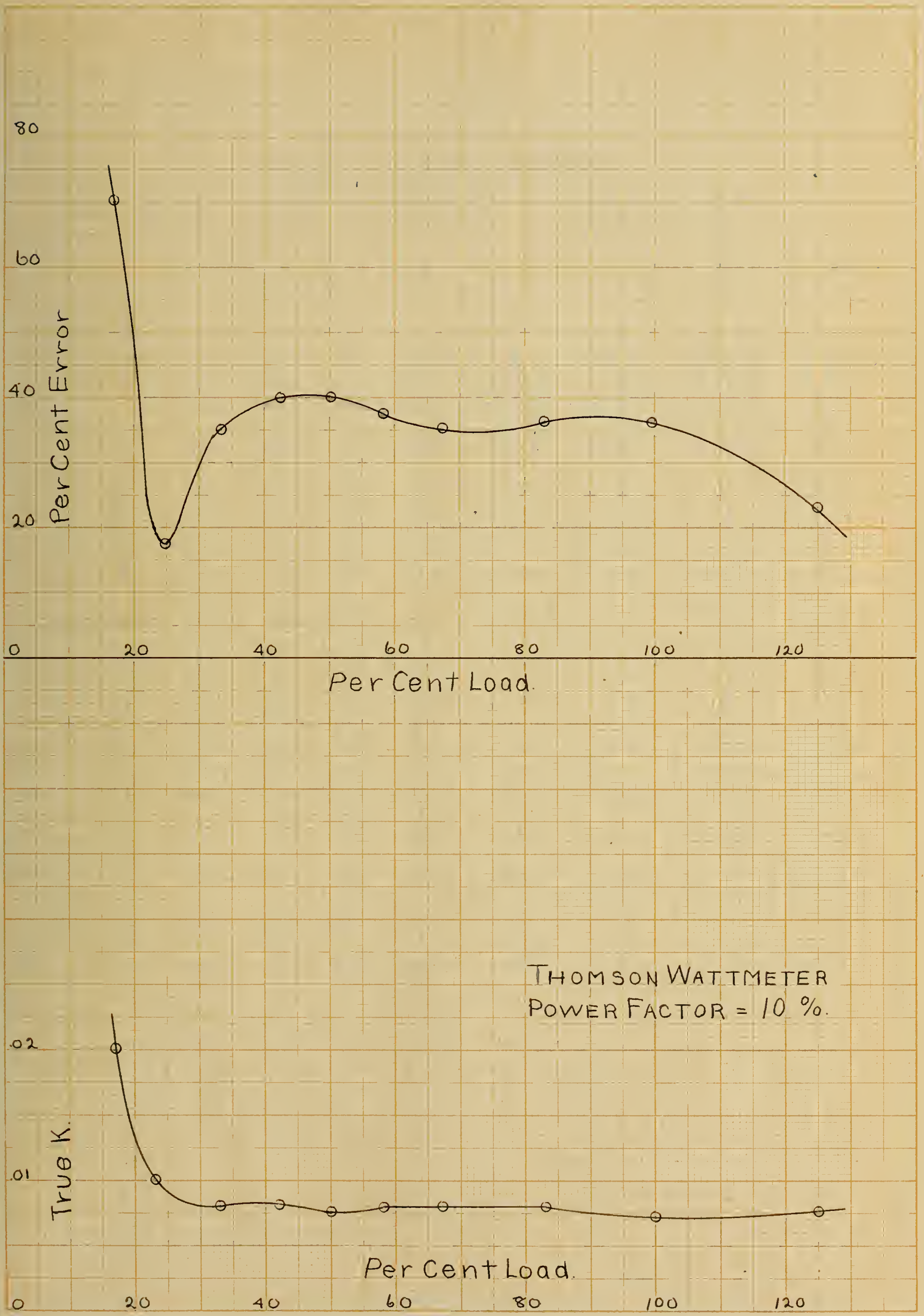
U OF S S FORM


Per Cent Error
40
20
0
20
40
60
80
100
120
Per Cent Load
THOMSON WATTMETER
POWER FACTOR = 40 %
.02
.015
.01
True K
Per Cent Load
0
20
40
60
80
100
120


THOMSON WATTMETER
POWER FACTOR = 30 %


Per Cent Error
40
20
0
20
40
60
80
100
120
Per Cent Load
THOMSON WATTMETER
POWER FACTOR = 20%
.02
.015
.01
True K
Per Cent Load
0
20
40
60
80
100
120

U OF I S S FORM



THOMSON WATTMETER
POWER FACTOR = 10 %.

U OF S S FORM

THOMSON RECORDING WATTMETER.

Calibration Power factor=100% . Meter K= .125

Time in Sec.	Rev. of Disc.	I	E	W	% P.F.	K	Error	% Error	% Load I
64	7	.47	110	55	100	.1395	-.0145	-11.6	15.5
66	11	.65	110	78	100	.130	-.005	- 4.	21.6
45	10	.9	110	100	100	.125	0	0	30
50.2	13	.96	110	113	100	.121	-.004	3.2	32
45.4	13	1.2	110	132	100	.127	-.003	-2.4	40
52.2	18	1.38	110	155	100	.125	0	0	46
48.8	18	1.5	110	164.3	100	.124	.001	.8	50
54	24	1.75	110	194.5	100	.122	.003	2.4	58.3
60	30	2.00	110	220	100	.122	.003	2.4	66.7
61	34	2.25	110	245	100	.122	.003	2.4	75
59	38	2.5	110	276	100	.119	.006	4.8	83.3
60.6	42	2.74	110	301	100	.120	.005	4	91.3
62.4	48	2.99	110	328	100	.119	.006	4.8	99.7
63	70	3.75	110	413	100	.103	.022	17.6	125.

THOMSON WATTMETER.

Power factor=90% . Meter K=.125.

Time in Sec.	Rev. of Disc.	I	E	W	% P.F.	K	Error	% Error	% Load I
57.2	5	.5	110	50	91	.158	-.033	-26.4	16.65
54.	10	.70	110	70	91	.105	.02	16.	23.3
57.4	12	1.0	110	99	90	.1325	-.0075	-6	33.3
55.2	16	1.25	110	123.5	90	.1185	.0065	5.2	41.7
61.6	20	1.5	110	148.	89.5	.126	-.001	-.8	50.
50.	20	1.75	110	175	91	.122	.003	2.4	58.5
60.2	26	1.98	110	194.5	89.5	.125	.000	0	66.
60.2	30	2.25	110	224	90.5	.125	.000	0	75.
63.	35	2.5	110	245	89.	.1225	.0025	2	83.5
61.	39	2.88	110	285	90	.1235	.0015	1.2	96.
52.0	36	3.18	110	315	90	.1245	.0012	.96	106
57.4	48	3.75	110	375	90	.1262	-.0005	-.40	125

THOMSON RECORDING WATTMETER.

Power Factor=80 %. Meter K= .125

Time in Sec.	Rev. of Disc	I	E	W	% P.F.	K	Error	% Error	% Load I
58.2	6	.5	110	44	80	.119	.006	4.8	16.7
61.8	8	.75	110	66	80	.142	-.017	-13.6	25
63	12	1.0	110	88.5	80.5	.129	-.004	- 3.2	33.3
61.6	14	1.25	110	109	79.4	.133	-.008	- 6.4	41.7
59	17	1.5	110	132	80	.127	-.002	- 1.6	50
58	20	1.75	110	155	80.5	.125	0	0	58.3
57	26	2.0	110	177	80.5	.108	.017	13.6	66.7
61	33	2.5	110	220	80	.113	.012	9.6	83.3
57	38	3.0	110	266	80.6	.111	.014	11.2	100.
59.2	48	3.75	110	330	80	.113	.012	9.6	125.

THOMSON RECORDING WATTMETER.

Power Factor=70 %.   Meter K=.125

Time in Sec.	Rev. of Disc	I	E	W	% P.F.	K	Error	% Error	% Load I
65	6	.5	110	38.5	70	.116	.009	7.2	16.65
61	8	.75	110	57.5	69.7	.1215	.0035	2.8	25
61	11	1.0	110	77	70	.1185	.0065	5.2	33.3
60.6	13	1.25	110	96	69.7	.124	.001	.80	41.7
60	18	1.5	110	116.5	70.5	.108	.017	13.6	50
60.2	21	1.75	110	136.5	71	.1085	.0165	13.2	58.5
59	23	2.0	110	154	70	.110	.015	12.0	66.8
60	28	2.5	110	192	70	.1142	.0108	8.6	83.5
62.4	36	3.0	110	230	69.7	.1105	.0145	11.6	100.
59.6	43	3.75	110	288	69.8	.111	.014	11.2	125

THOMSON RECORDING WATTMETER.

Power factor=60%　　　　Meter K=.125

Time in Sec.	Rev. of Disc	I	E	W	% P.F.	K	Error	% Error	% Load I
58.6	4	.5	110	33	60	.134	-.009	-7.2	16.7
57.6	7	.75	110	50	60.6	.114	.011	8.8	25.
62.8	10	1.00	110	66	60	.115	.010	8.	33.3
58.4	12	1.25	110	82	59.6	.111	.014	11.2	41.7
59.6	14	1.5	110	98	59.4	.116	.009	7.2	50.
60.2	17	1.75	110	116	60.3	.114	.011	8.8	58.3
59.6	20	2.0	110	131	59.5	.108	.017	13.6	66.7
56.2	24	2.5	110	164.5	60.	.107	.018	14.4	83.3
58.6	30	3.0	110	200	60.7	.1085	.0165	13.2	100.
60	38	3.75	110	247	59.8	.108	.017	13,6	125

THOMSON RECORDING WATTMETER.

Power factor=50% Meter K=.125

Time in Sec.	Rev. of Disc.	I	E	W	P.F.	% K	Error	Error	% Load I
67.8	4	.5	110	27.5	50	.1295	-.0045	-3.6	16.7
59.8	6	.75	110	41.	49.7	.1135	.0115	9.2	25.
56.8	8	1.0	110	55.5	50.4	.1093	.0157	12.5	33.3
61.2	11	1.25	110	68.75	50	.106	.019	15.2	41.7
57.4	12	1.5	110	82.	49.7	.1088	.0162	13.	50.
56.8	14	1.75	110	96.	49.8	.108	.017	13.6	58.3
59.4	17	2.0	110	110	50	.1068	.0182	14.5	66.7
61.6	22	2.5	110	136	49.5	.1058	.0192	15.4	83.3
61.4	28	3.0	110	165	50	.1007	.0243	19.4	100.
60.0	34	3.75	110	209	50.7	.1025	.0225	18.	125.

THOMSON RECORDING WATTMETER.

Power factor=40% . Meter K=.125

Time in Sec.	Rev. of Disc.	I	E	Watts	% P.F.	K	Error	% Error	% Load I
72	4	.5	110	22	40.	.1095	.0155	12.4	16.65
59	5	.75	110	33.5	40.5	.110	.015	12	25
59	7	1.00	110	45	40.8	.1055	.0195	15.6	33.3
57	8	1.25	110	55	40.	.1088	.0162	12.95	41.7
58.2	10	1.5	110	65.6	39.8	.1065	.0185	14.8	50
57.2	12	1.75	110	77.5	40.5	.103	.022	17.6	58.3
59.	14	2.0	110	88.	40.	.103	.022	17.6	66.7
59.8	16	2.5	110	110.	40.	.1142	.0108	8.6	83.3
59.8	22	3.0	110	133.	40.3	.1005	.0245	19.6	100
56.8	26	3.75	110	164.	39.8	.0995	.0255	20.4	125

THOMSON RECORDING WATTMETER.

Power Factor=30%   Constant =.125

Time in Sec.	Rev. of Disc.	I	E	Watts	% P.F.	K	Error	% Error	% Load I
69.2	3	.5	110	16.5	30	.1058	.0192	15.35	16.7
58	4	.75	110	24.5	29.7	.099	.026	20.8	25
54.6	5	1.00	110	33.5	30.4	.1015	.0135	10.8	33.3
58	6	1.25	110	41.	29.8	.110	.015	12.0	41.7
58	8	1.5	110	49.5	30	.100	.025	20	50.
56.4	9	1.75	110	57.5	29.8	.100	.025	20	58.3
56	10	2.0	110	65.	29.5	.101	.014	11.4	66.7
59.0	14	2.5	110	83.	30.1	.097	.028	22.4	83.3
57.4	16	3.0	110	100.	30.3	.0997	.0253	20.2	100.0
56	20	3.75	110	124.5	30.2	.097	.028	22.4	125.

THOMSON RECORDING WATTMETER.

Power factor =20% . Meter K=.125.

Time in Sec.	Rev. of Disc.	I	E	Watts	% P.F.	K	Error	% Error	% Load I
61.4	2	.5	110	11	20	.094	.031	24.8	16.7
67	3	.75	110	16.5	20	.1022	.0228	18.2	25.
50.6	3	1.00	110	22.5	20.4	.1055	.0195	15.6	33.3
60	5	1.25	110	28	20.3	.0935	.0315	25.2	41.7
61	5	1.5	110	33.5	20.3	.095	.035	28.	50.
59.4	7	1.75	110	39.0	20.2	.092	.033	26.4	58.3
62.0	8	2.00	110	44.0	20.	.0947	.0303	24.2	66.7
60	10	2.5	110	56.0	20.3	.0933	.0317	25.4	83.3
67	12	3.0	110	67.0	20.2	.0885	.0365	29.2	100.0
57.4	15	3.75	110	83	20.1	.0883	.0367	29.4	125.0

THOMSON RECORDING WATTMETER.

Power factor=10%.   Meter K=125

Time in Sec.	Rev. of Disc.	I	E	Watts W	% P.F.	K	Error	% Error	% Load I
131.4	1	.5	110	5.5	10	.201	-.076	-60.8	16.7
46.0	1	.75	110	8.25	10	.1055	.0195	15.6	25
51.4	2	1.00	110	11	10	.0785	.0465	37.2	33.3
62.0	3	1.25	110	13.75	10	.079	.046	36.8	41.7
63.0	4	1.5	110	17	10.3	.0745	.0505	40.5	50
55.6	4	1.75	110	19.5	10.1	.0755	.0495	39.6	58.3
62.[illegible]	5	2.00	110	22.5	10.2	.0778	.0462	37.0	66.7
58.4	6	2.5	110	28.5	10.3	.077	.048	38.4	83.3
54	7	3.0	110	34.	10.3	.073	.052	41.6	100
62.4	10	3.75	110	43.	10.4	.0745	.0505	40.5	125

GENERAL DISCUSSION:

For constant power factor the torque is directly proportional to the current, and the friction varies as some unknown power of the speed. The ratio of torque to friction will vary in some uncertain way, hence the accuracy of the indications of the meters will be variable at different loads. The error in general being greater at the lower loads. The uncertainty of the ratio of friction to torque at various loads will account in a measure for the irregularities of the curve at various loads at a given power factor. The irregularity will be more pronounced for iron in the circuit as can be seen from the inspection of the curves of the various meters.

For constant loads and varying P. F. the torque will vary as the $\cos(\theta+\phi)$, ϕ being the constant angle due to the pressure circuit. As the power factor of the external circuit decreases, θ decreases, Hence the torque will tend to decrease as a known function of the power factor. This is not the case however, as the constant angle ϕ bears an unknown ratio to the whole angle of torque. At lower power factors the effect of the angle ϕ upon the whole angle will be greater; hence while the general effect will be to decrease the torque at the lower factors. The actual variation of the torque will be uncertain owing to the unknown effect of the constant angle ϕ on the whole torque angle. This uncertainty will vary for the pressure circuits of the several meters. Hence it accounts for the variation of the curves of the different meters. As a general thing for the meters having iron in their circuits, the errors are negative, while for the commutator

type the errors are positive.

CONCLUSIONS.

After comparing the "per cent of error "curves, the general conclusion is, that the Thomson meter (commutator type) has the greatest general accuracy for the same variations of load and power factor. It is also to be noted that for the higher power factors there is little choice between the mercury and the induction meter as both have about the same average per cent of accuracy. On low power factors the mercury meter shows the greater accuracy, as regard indication of true energy passing through the circuit if the direction of rotation of the disc is neglected. With a registering device made to run one way, on low power factors the mercury meter would be entirely unsatisfactory since it runs backwards, subtracting from the previous registrations of the meter instead of adding to it as it should do.

Owing to the irregular and uncertain variation of the ratio of torque to friction, it does not seem probable that any device may be added to the meters, to entirely compensate for the effect of power factor, as such a device would have to be adjusted for every variation of power factor or load.

UNIVERSITY OF ILLINOIS-URBANA
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